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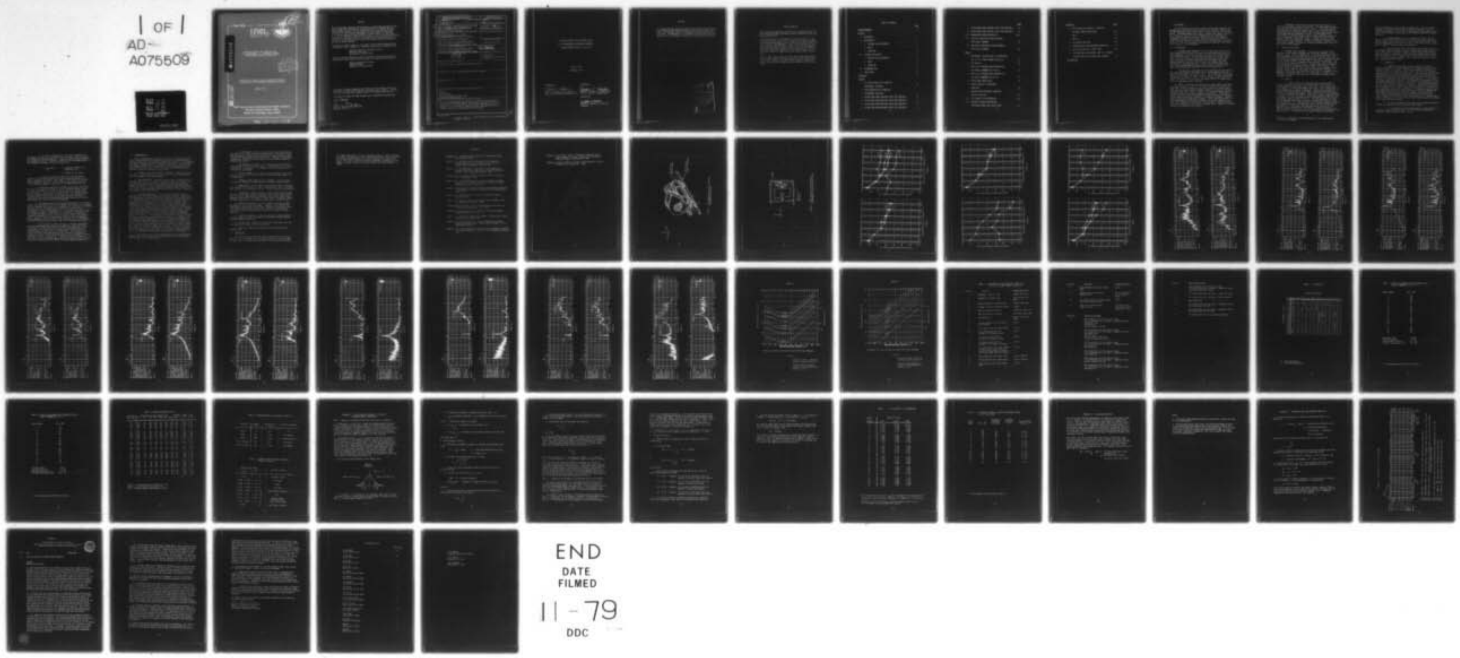

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BASELINE ACOUSTIC AND VIBRATION STUDY OF THE MINUTEMAN II (INTEGRATED PROGRAM) LAUNCH CONTROL CENTER, WS-133B (IP)

Approved for public release; distribution unlimited

January 1979

USAF Occupational and Environmental Health Laboratory
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

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FOR THE COMMANDER

Dennis J. Muser

DENNIS J. MUSER, Major, USAF, MSC
Executive Officer

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This report presents baseline acoustic and vibration data acquired in a Minuteman[II](Integrated Program) Launch Control Center (WS-133B). No hazardous levels for exposures of up to 24-hour duration were found. Recommendations are provided to reduce the levels compatable with an environment suitable for long-duration crew alerts.

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BASELINE ACOUSTIC AND VIBRATION STUDY
OF THE MINUTEMAN [II] (INTEGRATED PROGRAM)
LAUNCH CONTROL CENTER, WS-133B (IP)

January 1979

USAF OEHL 79-10

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This report presents baseline acoustic and vibration data acquired in a Minuteman [II](Integrated Program) Launch Control Center (WS-133B). No hazardous levels for exposures of up to 24-hour duration were found. Recommendations are provided to reduce the levels compatable with an environment suitable for long-duration crew alerts.

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LIMITING VALUE FOR 24-HOUR NOISE EXPOSURE E-1

DISTRIBUTION

I. BACKGROUND:

At the request of HQ SAC/SG, baseline acoustic and vibration measurements were conducted during the period 11-14 September 1978 in the 448 SMS Minuteman[II](IP) Launch Control Center (LCC) K-0 at Grand Forks AFB ND. These measurements were made to identify the sources of noise and vibration in the LCC and to recommend practical techniques for noise/vibration reduction, thereby improving the crew environment. Crewmembers presently stand 24-hour continuous duty alert tours, but there is active interest in transitioning to a 48-hour tour. Thus the condition of the LCC environment has become more important with respect to its impact on crew performance.

II. MEASUREMENTS:

A. PERSONAL NOISE DOSIMETRY: Prior to the acquisition of baseline acoustic/vibration data, personal noise dosimeters were worn by both crewmembers serving in the LCC K-0 in order to determine baseline crew exposure to noise. The dosimeters were worn for 16 hours (two units, each for a separate 8-hour period) during each 24-hour alert tour. The number of alerts during which the dosimeters were worn depended upon the stability of the acoustic environment and on the consistency of the acquired data. Criteria for deciding when data acquisition was completed are based on the Student's t-statistic for small sample populations (outlined in Part I of Appendix A).

The dosimeter accumulates the noise exposure over the measurement time and integrates the levels into a single number called the Equivalent Continuous Sound Level (ECSL). The integration is performed using a 4-dB exchange rate and a criterion level of 84 dBA in accordance with AFR 161-35, Table 3. That is, the percentage exposure doubles for every 4 dB increase in sound level and equals 100% for an 8-hour exposure to a continuous level of 84 dBA.

B. NOISE: Baseline octave-band acoustic measurements were made at various locations in the LCC. In order to obtain the required test conditions, it was necessary to take the LCC off alert status, power-down, and selectively restore equipment operation or exercise selected equipment (e.g., SDR printer). Table 1 lists the measurement locations and test conditions as numeric/alphabetic designators. A particular combination of the types of equipment that were operating constituted a unique condition which was assigned an alphabetic designator. Measurement locations were identified by number. Table 2 provides a matrix of these measurement locations/test conditions to readily summarize the test plan. Appendix B discusses the "dB" notation including the definition of sound pressure level and its reference value. Appendix D provides guidance in reading the strip charts.

C. VIBRATION: Narrow-band constant-percentage bandwidth (3%) vibration measurements were also performed. The measurement locations/test conditions are included in Tables 1 and 2. Certain measurement locations are also shown in Figures 1 and 2. The vibration data are reported mostly as root-mean-square (rms) vibratory acceleration levels (dB) though some are reported as velocity or displacement levels. Definitions of vibratory levels as well as their reference values are given in Appendix C, paragraphs 1 and 2. Paragraph 3 of this same appendix gives the conversions between rms, peak, and peak-to-peak levels at any single frequency. Finally, paragraph 4, Appendix C shows the relation between the three rms vibratory variables (not levels in dB) at any single frequency.

III. FINDINGS/DISCUSSION:

A. PERSONAL NOISE DOSIMETRY: The results of personal noise dosimetry on the capsule commander and the deputy commander are presented in Tables 3 and 4, respectively. The average exposure level for both crewmembers is 78 dBA over the 24-hour alert period, with a 95% confidence that the true average exposure level does not exceed 80.0 dBA for the capsule commander and 80.3 dBA for the deputy commander. The criteria in AFR 161-35, "Hazardous Noise Exposure", do not cover exposure durations longer than 16 hours. However, they imply an exposure limit of 80 dBA for exposure durations greater than 16 hours. Also, exposures of up to 84 dBA for 24 hours would not cause damage if sufficient recovery time (at least equal to the exposure duration) is allowed. These points are discussed in some detail in Appendix E (6570 AMRL/BBA letter dated 2 May 1977, "Limiting Value for 24-Hour Noise Exposure"). Based on these two facts, there does not appear to be a hazard to hearing.

B. NOISE:

1. Table 5 gives the octave-band sound pressure levels, overall sound pressure levels, A-weighted overall sound levels, and Preferred Speech Interference Levels (PSIL)* for the locations/conditions (Table 1) at which measurements were made. Some of these data are shown graphically in Figures 3 through 8. Notice that the acoustic energy in the low frequency octave-bands (especially the band centered at 31.5 Hz) dominates the spectra. Referring to Table 5, the similarity of levels in the 31.5 Hz to 250 Hz octave-bands between condition A and conditions H, I and K indicates the Air Conditioning Unit (A/C) may be the primary source of noise in the LCC. The Motor-Generator Set (MG) was not measured alone since it could not be operated without cooling air from the A/C. It is possible that the A/C and the MG could be equal contributors of noise. Elimination of one or the other should cause approximately a 3-dB drop in the measured levels, but this is not apparent from an examination of the spectra. Another possibility is that the MG emits most of its noise in a frequency range different from that of the A/C. A comparison of the higher frequency octave-band

*The PSIL is a measure of the effectiveness of voice communication in a noise environment.

levels of conditions E and K seems to support this. That is, the A/C produces noise primarily below 250 Hz (probably dominant at the fan rotational frequency of 30 Hz) and the MG produces noise primarily above 500 Hz. More evidence is available in the vibration analysis of these two units.

2. The Room Heater fan (RH), UHF Radio Set (UHF), and the Battery Charger (BC) noise appear in the upper octave-bands starting at 500 Hz (compare conditions D, E and F with L) and readily blend in with the A/C and MG noise. Both the RH fan and the UHF fan noise are noticeable at specific locations (both crew consoles).

3. The SDR Printer (SDR) contributes about 6 dBA to the noise environment around the deputy's console (compare measurement 3/A with 3/B). Also, at this location, the PSIL increases from 61 dB to 69 dB when the printer is operating. Furthermore, the communication environment for telephone use is degraded from "slightly difficult" to "difficult", and for satisfactory speech, from a "very loud voice at 10 feet" to a "shouting voice at 8 feet".

C. VIBRATION:

1. Measured narrow-band vibration spectra are shown in Figures 9 through 28. All measurements were of RMS acceleration unless otherwise noted on the figure. There are two predominant sources of vibration in the Air Conditioning Unit (A/C): The fan shaft unbalance characterized by a radially-directed force at the shaft rotating frequency (approximately 30 Hz); and the aerodynamic forces resulting from the passage of the fan blades past the duct opening (in the scroll), characterized by a frequency at the blade passage frequency (i.e., 48 blades x 1750 rpm divided by 60 = 1400 Hz). The strong 30 Hz peak appears in the measurements made directly on the A/C and on its plenum panels (locations 10, 11, 12, 13, and 19, Figures 11 through 20). The blade passage peak appears around 1400 Hz at location 10, weakly at location 11, and not at all at locations 12, 13, and 19, because this vibration is not strong in the X-direction (location 11) and because it is decoupled from the other measurement locations by four internal vibration isolators between the fan assembly mounting base and the fan assembly support structure. These isolators provide about 18 dB of attenuation (condition 10/A vs 12/A) or about 87% isolation at 30 Hz which appears fair. However, much better isolation (e.g., 24 dB or 94% isolation) could possibly be achieved using a more efficient isolator.

2. In the Motor-Generator Set (MG) structure-borne vibrations (Figures 21 through 24) result from three main causes:

a. An unbalance of the rotating parts, characterized as a rotating, radially-directed force, and occurring at the rotational frequency (1800 rpm divided by 60 = 30 Hz).

b. Elliptical deformation of the stator laminations by the magnetic forces across the rotor-stator air gap as the rotor turns. The frequency of these deformations is twice the power-supply frequencies (60 and 420 Hz) and their harmonics, especially the odd-numbered ones. The fundamental frequency can be calculated from

$$f = \frac{nP}{60}, \text{ where } \quad n = \text{rotational speed of the generator, rpm}$$

$$P = \text{number of rotor poles.}$$

c. Bearing vibrations in the form of random impacts caused by too much radial play; or frictional grinding caused by too tight a clearance, worn balls, rough races, or too viscous or an insufficient amount of lubricant. Such vibrations are characterized by a lack of discrete frequencies and occur in the range 250 Hz to 5 kHz.

3. The machine condition of the MG in the radial (14/L) and axial (15/L) directions is shown for several vibration maxima in Table 6. Table 7 provides criteria of vibration severity for various RMS velocity ranges. Overall, while the MG appears to be running normally, and the vibrations transmitted to the MG box wall are reduced by about 28 dB and about 16 dB at 30 Hz in the radial and axial directions respectively, the structure-borne vibrations and radiated noise are at undesirable levels which can be further reduced.

4. The hum emitted by the iron-core transformer in the Battery Charger (BC) connected to the 60 Hz AC supply lines consists of a harmonic range of component tones based on a fundamental of twice-the-line frequency. The main cause is the magnetostrictive effect (change in length of ferromagnetic materials when magnetized) in the transformer core. Since this change in length is independent of the direction of magnetization, two changes per magnetization cycle occur, which produce the twice-frequency fundamental (120 Hz) of the resultant vibration and radiated sound. Figure 27 shows this phenomenon at location 18, the harmonics being numbered for ease of reading. The vibration level is very low and presents no problem, especially with the other strong sources persent.

5. With respect to human exposure to vibration, man/support interface measurements were made at the Commander's Seat (2/A) and in the middle of the bed (7/A) while occupied by a 180-pound male. The accelerometer was attached to a one-quarter-inch thick steel plate installed under the back side of the individual. In the case of the seated individual, the measurement reflects vertical (longitudinal) acceleration, while for the reclining position, the measurement reflects horizontal (lateral) acceleration. In both instances, the exposure falls well below the "Reduced Comfort Boundary" criteria given in Figures 29 and 30 in the region 1 Hz to 80 Hz for 24-hour exposure durations.

IV. RECOMMENDATIONS:

These recommendations are not all inclusive. There may be others which are more effective for performance, but the ones offered below represent practical, cost-effective engineering controls. It is suggested that these recommendations be implemented incrementally, starting with the cheapest, easiest fixes, progressing up through the more difficult, extensive and costly ones. In this way, one may adequately gauge the progress of the control effort at each stage.

A. ENTRANCE TO THE LCC ACOUSTICAL ENCLOSURE: Install an acoustical curtain constructed of mass-loaded vinyl as an accordian-type door. Seal the threshold at the door entrance.

B. MOTOR-GENERATOR: Vibration-isolate the unit from the motor-generator box; 30 Hz is the lowest frequency of the driving force. Also line the motor-generator box with 2-inch-thick fiberglass sandwiched between the box wall and 16 to 18-gauge perforated sheet steel (approximately 30% porosity) to help attenuate reverberant sound present in the box. Seal all holes and chink cable-access holes in the box. Check and lubricate or replace the bearings.

C. AIR CONDITIONING UNIT: Clean the fan blades and scroll; statically and dynamically balance the fan-motor assembly. Perform an Air Flow Balance procedure and adjust as necessary to allow operation to a filter blockage of 0.5 inch w.g. rather than 0.75 inch to 0.85 inch w.g. currently being used. This will require more frequent filter changes as well as redesignation of the Safe/Unsafe indicator marks on the Magnahelic differential pressure gauge. Calibrate this gauge. Stiffen the lower plenum access panels by the attachment of cross beams (angle iron) onto the panels using either spot welds or bolts. Realign/replace aged flexible duct connection material. Where possible, line the lower plenum panels with 1 1/2-inch-thick fiberglass sandwiched between the panel and 16 to 18-gauge perforated sheet steel (approximately 30% porosity). Consider replacing the present vibration isolators with new ones designed to provide better isolation. For example, with an isolator having a damping factor of 0.10, the natural frequency of the isolated system would decrease from the present 10 Hz to 6 Hz, the isolator static deflection would increase from about 0.1 inch to about 0.4 inch, and the structure-borne noise reduction would increase from 18 dB to 24 dB, or from 87% to about 94% isolation. Finally, it also may be necessary to install a rectangular duct silencer in the main outlet duct. This should be reserved until all other noise reduction measures on the A/C have been concluded and further reduction is desirable.

D. CABLE ACCESS HOLE IN THE FLOOR BETWEEN THE BED AND THE BATTERY CHARGER RACK: Install a lead boot around the cables to seal the hole. Chink in cracks with fiberglass wool.

E. SLEEPING AREA: Install an acoustic enclosure constructed of mass-loaded vinyl along the perforated metal wall; solid walls at head and foot and on ceiling; and an accordian door across the aisle access. Vibration-isolate the bed frame from the floor. Replace the bed frame and mattress, preferably with one which has a box spring to provide adequate back support.

F. UHF RADIO SET: Install a seal on the rear edges (vertical only) between the UHF and MF radio sets. Although this fix is a significant reducer of annoyance, it is temporary, as the UHF Radio Set is scheduled for replacement.

G. BATTERY CHARGER: This system is not considered to be a significant contributor of noise in view of the other sources present. No recommendations.

H. OPENING IN WALL BEHIND THE SLFCS CABINET: Install acoustic curtains over opening; seal the openings to eliminate acoustic leaks.

I. ROOM HEATER: Install damper with bleed-off branch in the main duct upstream of the heater in order to reduce the air flow. Also open the louvers in the distribution outlets. A duct silencer may be necessary.

J. SDR PRINTER: Install an acoustic enclosure on the face plate similar to those used on business machines (e.g., as outlined in Attachment 5 of the 321 SMW Proposal, "Minuteman Lauch Control Center Noise Abatement Program Plan", 321 DO-01, 15 March 1978). Optionally, replace the SDR printer with a quiet-operating alpha-numeric thermal printer.

K. CARPETING IN AISLES: This will probably provide less than 1 dB reduction in the noise environment. However, it may improve the psychological environment for the crew. Offsetting any potential benefits may be problems associated with low humidity, creating static electricity, and it may not be cost-effective on the basis of noise reduction.

L. CHAIR SEAT CUSHION: Inspect and replace with new chushions, as the old ones lose their stiffness and resilience, thereby causing severe discomfort to the user.

M. HF RADIO SET: Install an acoustically-lined baffle over the fan inlet port on lower front of the cabinet.

N. SACCS SET: Adjust the clanger arm on the alarm bell for minimum noise.

V. CONCLUSIONS:

All the data contained in this report were acquired at only one LCC (i.e., K-0). However, they sufficiently represent the environment of other LCCs of the same class, WS-133B (IP), and therefore can serve

as a model toward which to direct improvement efforts. While no hazardous levels for exposures of up to 24-hour duration were found, the noise environment becomes marginal for exposure durations in excess of 24 hours. This fact, coupled with numerous complaints registered by crewmembers, indicate a need to reduce the ambient noise and vibration levels.

REFERENCES

Beranek, L.L., "Noise and Vibration Control," McGraw-Hill Book Co., New York, 1971.

Broch, J.T., "The Application of the Bruel & Kjaer Measuring Systems to Acoustic Noise Measurements," 2nd Ed., Bruel & Kjaer, Copenhagen, Denmark, 1971.

Broch, J.T., "The Application of the Bruel & Kjaer Measuring Systems to Mechanical Vibration and Shock Measurements," 2nd Ed., B & K, Copenhagen, Denmark, 1972.

Crocker, M.J., A.J. Price, "Noise and Noise Control," CRC Press, Inc., Cleveland OH, 1975.

Glew, C.A.W., "The Effectiveness of Vibration Analysis as a Maintenance Tool," Transactions of the Institute of Marine Engineers, London, Vol 86, 1974.

"Guide for the Evaluation of Human Exposure to Whole-Body Vibration," ISO 2631-1978, International Organzation for Standardization, 1978.

Harris, C.M., "Handbook of Noise Control," McGraw-Hill Book Co., New York, 1957.

Harris, C.M., and C.E. Crede, "Shock and Vibration Handbook," 2nd Ed., McGraw-Hill Book Co., 1976.

"Hazardous Noise Exposure," Air Force Regulation 161-35, Dept. of the Air Force, Washington, D.C., 1973.

"Industrial Noise Manual," 3rd Ed., American Industrial Hygiene Association, Akron OH, 1975.

Lapin, L.L., "Statistics - Meaning and Method," Harcourt Brace Jovanovich, Inc., New York, 1975.

Leidel, N.A., K.A. Busch and J.R. Lynch, "Occupational Exposure Sampling Strategy Manual," NIOSH Technical Report 77-173, Cincinnati OH, 1971.

Randall, R.B., "The Application of the Bruel & Kjaer Measuring Systems to Frequency Analysis," 2nd Ed., B & K, Copenhagen, Denmark, 1977.

Salmon, V., J.S. Mills, and A.C. Petersen, "Industrial Noise Control Manual," National Institute for Occupational Safety and Health, Cincinnati OH, 1975.

Thumann, A. and R.K. Miller, "Secrets of Noise Control," 2nd Ed., Fairmont Press, Atlanta Ga., 1976.

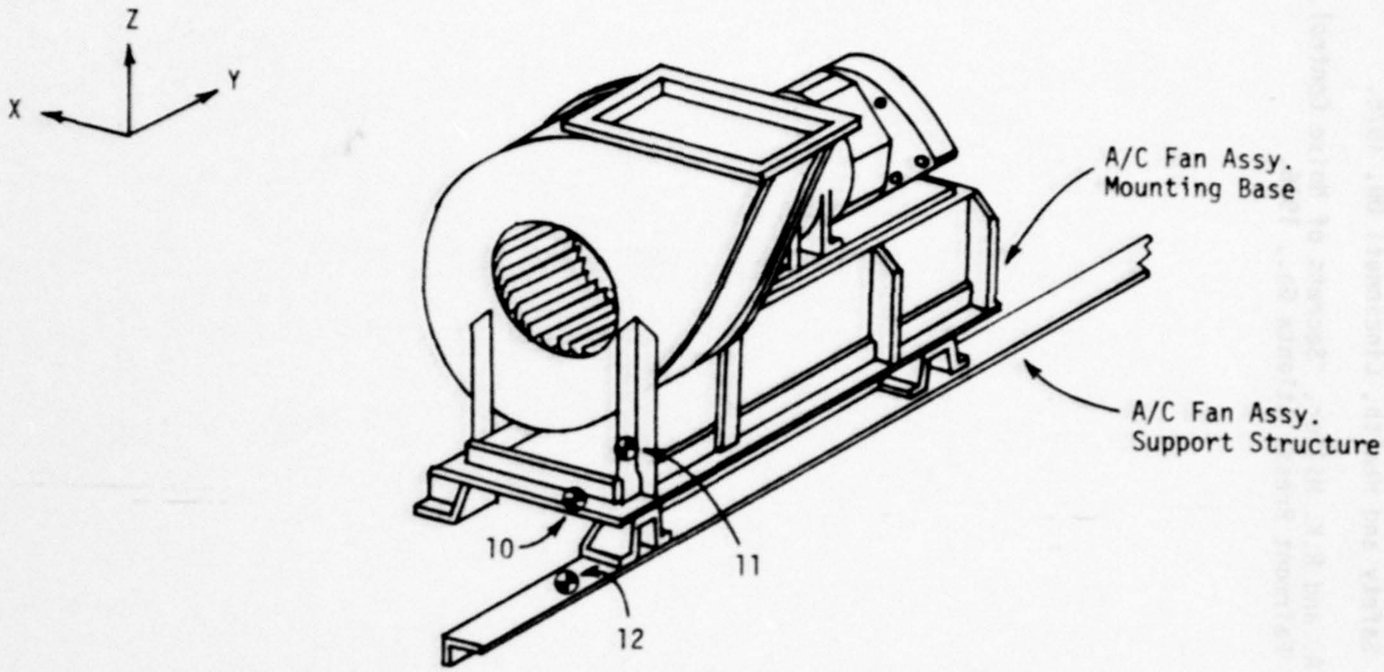


FIGURE 1 - AIR CONDITIONING UNIT VIBRATION
MEASUREMENT LOCATIONS

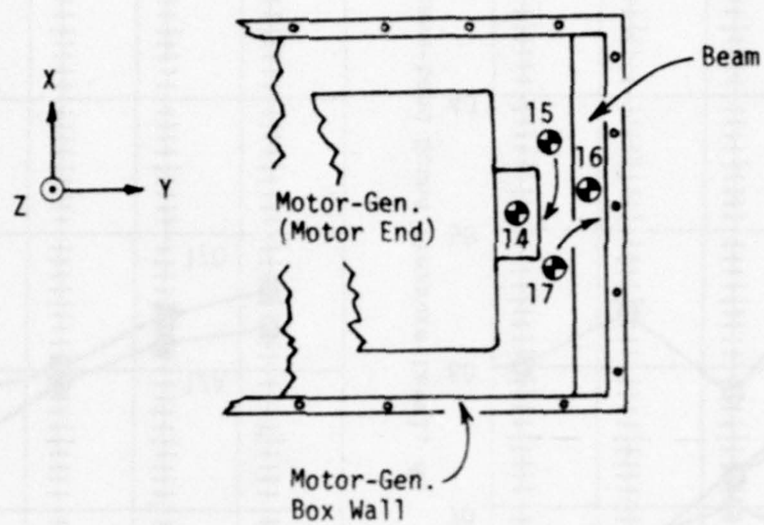


FIGURE 2 - MOTOR-GENERATOR SET VIBRATION MEASUREMENT LOCATIONS (PLAN VIEW)

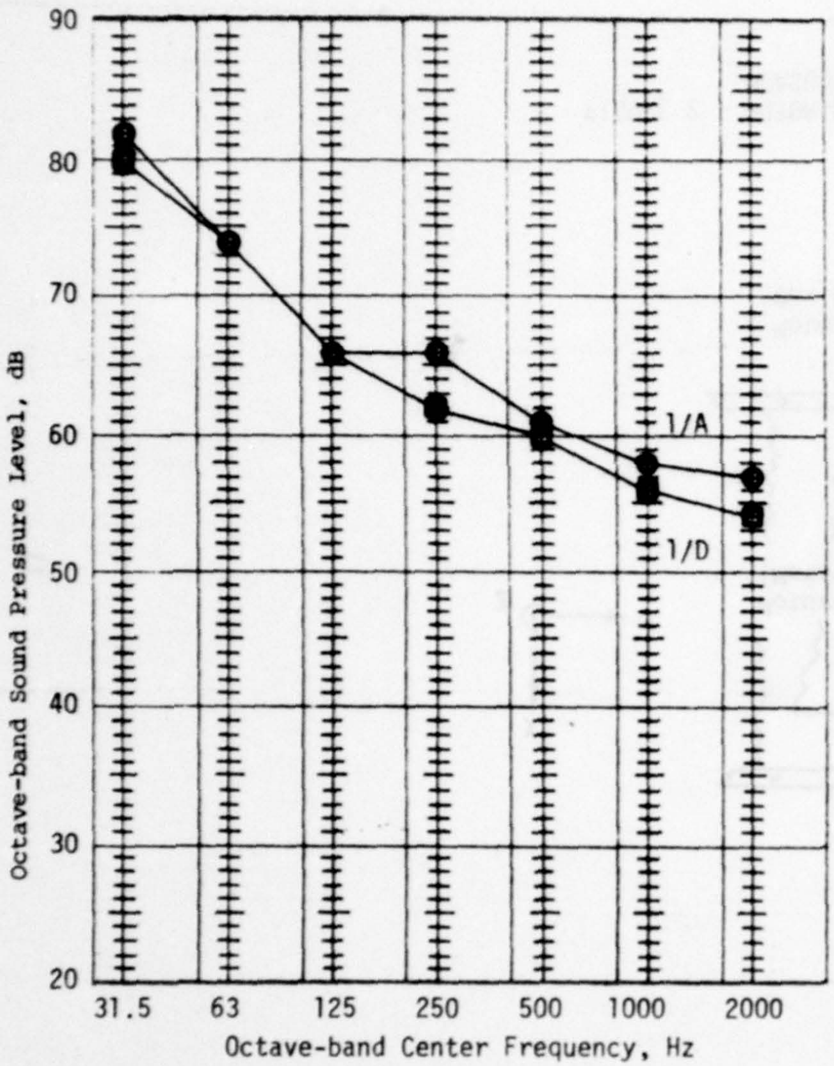
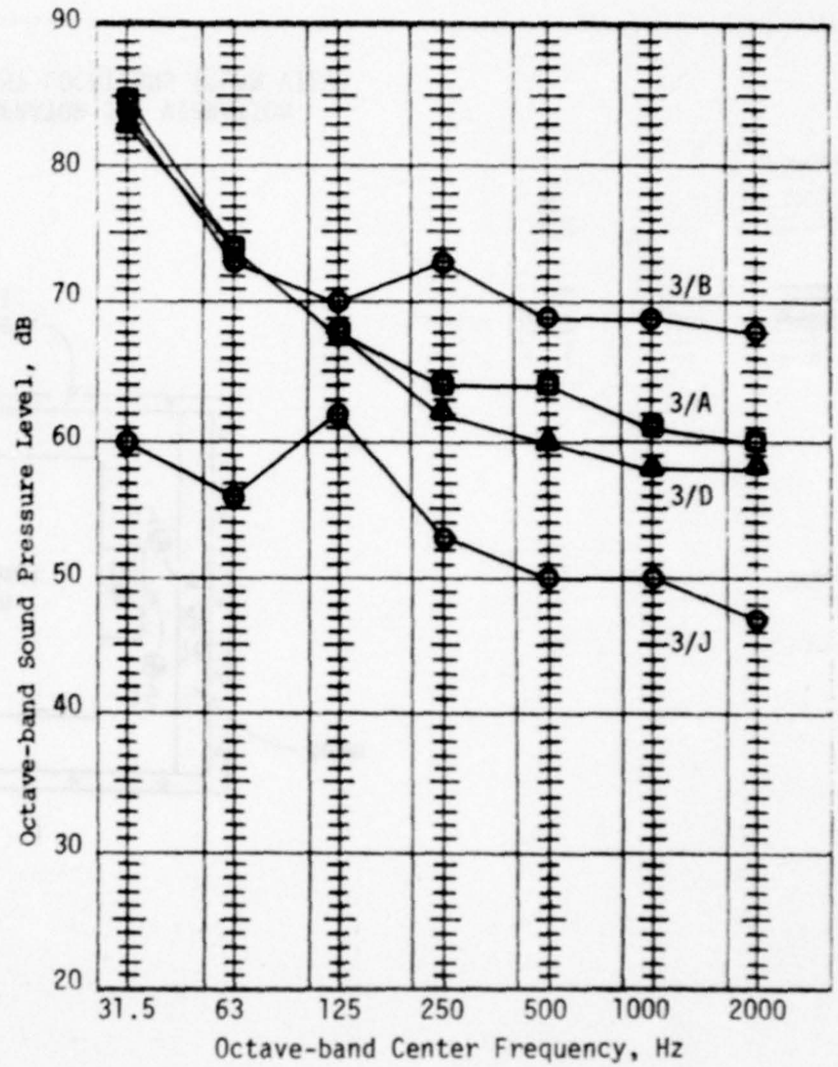


FIGURE 3



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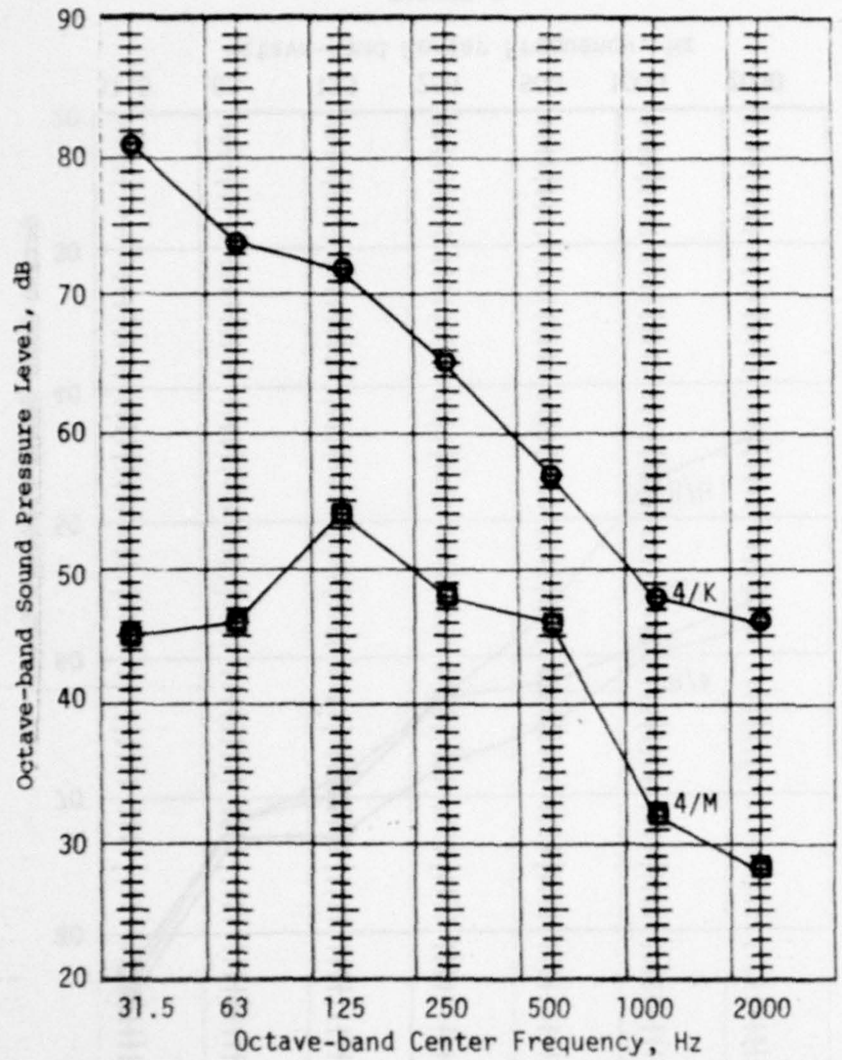

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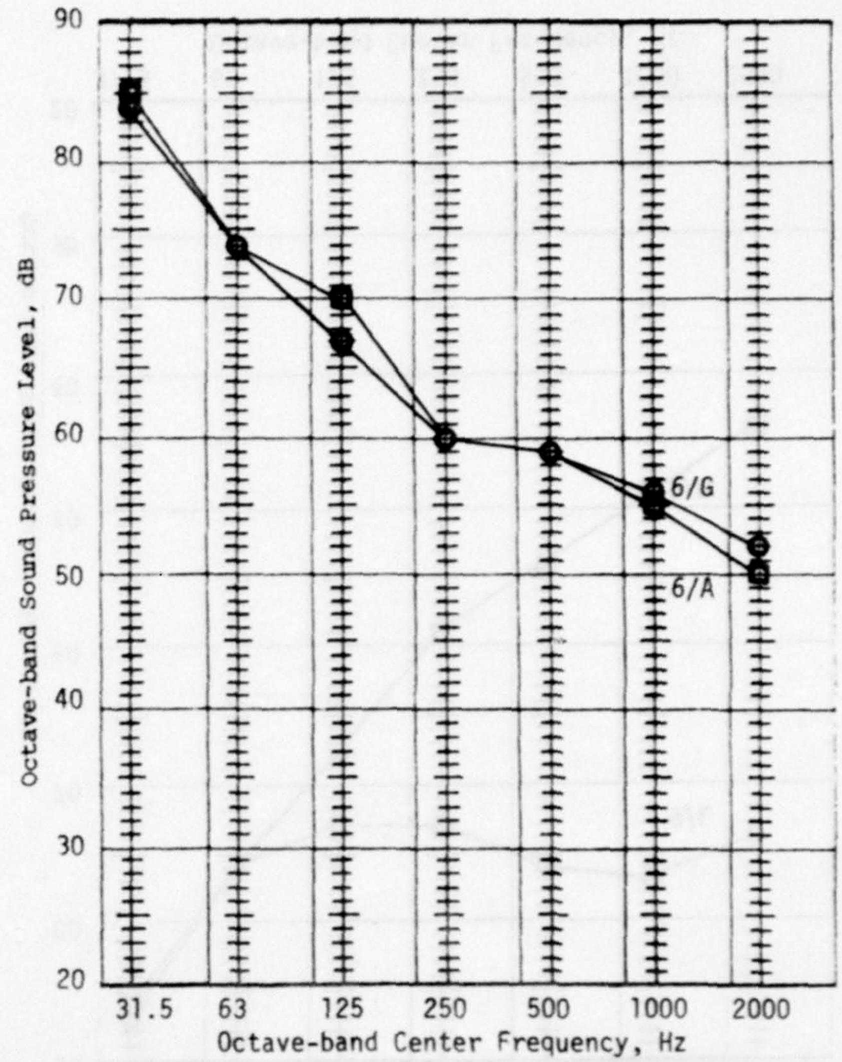

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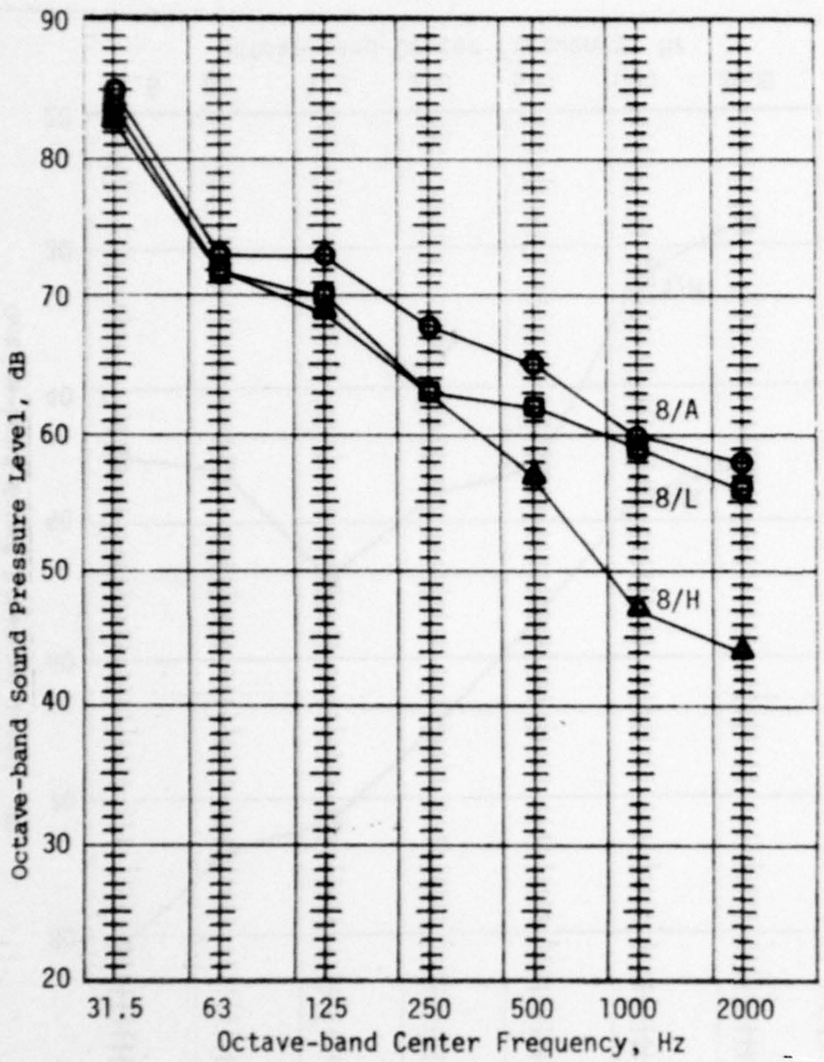

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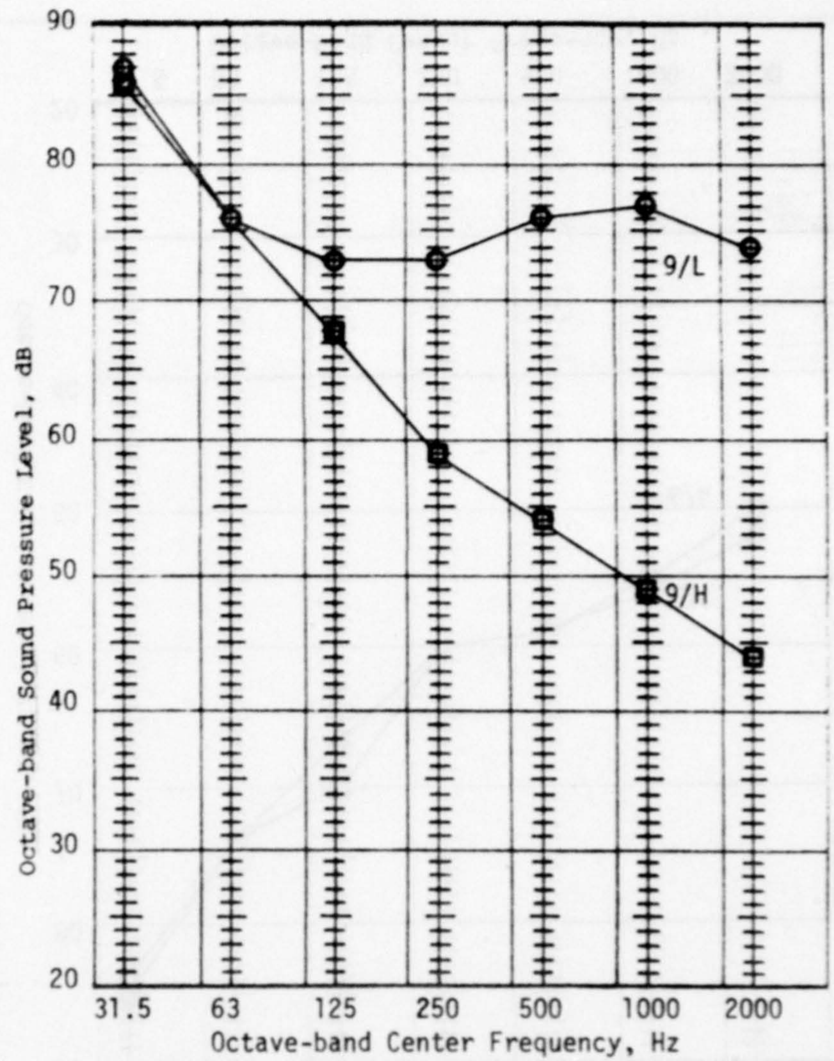

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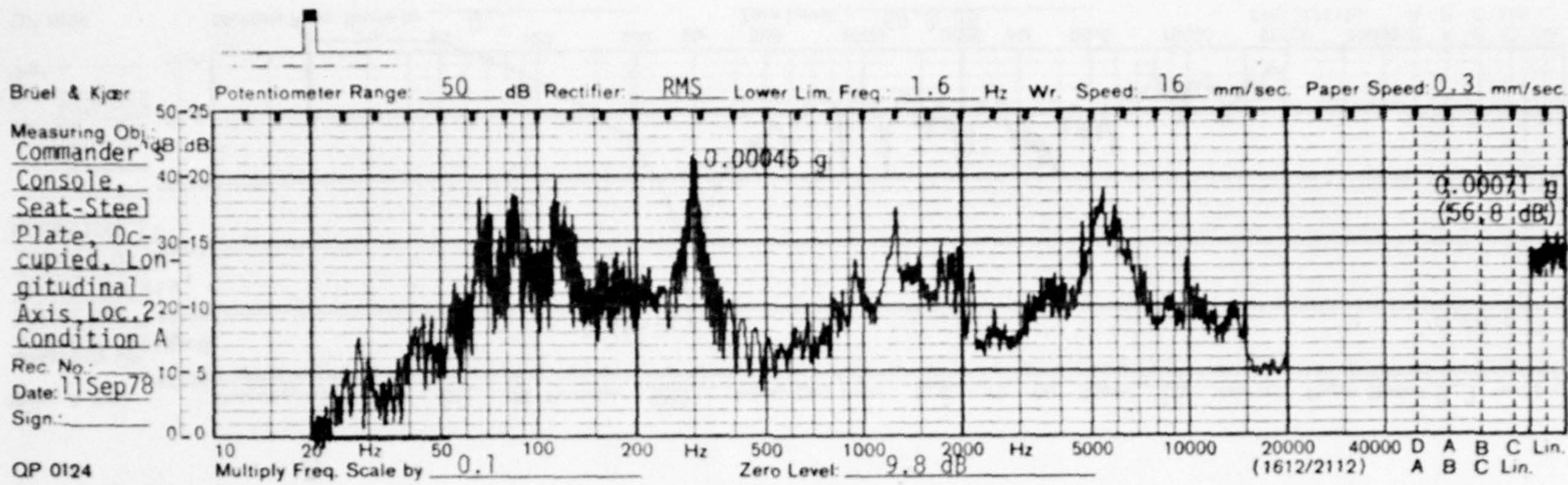

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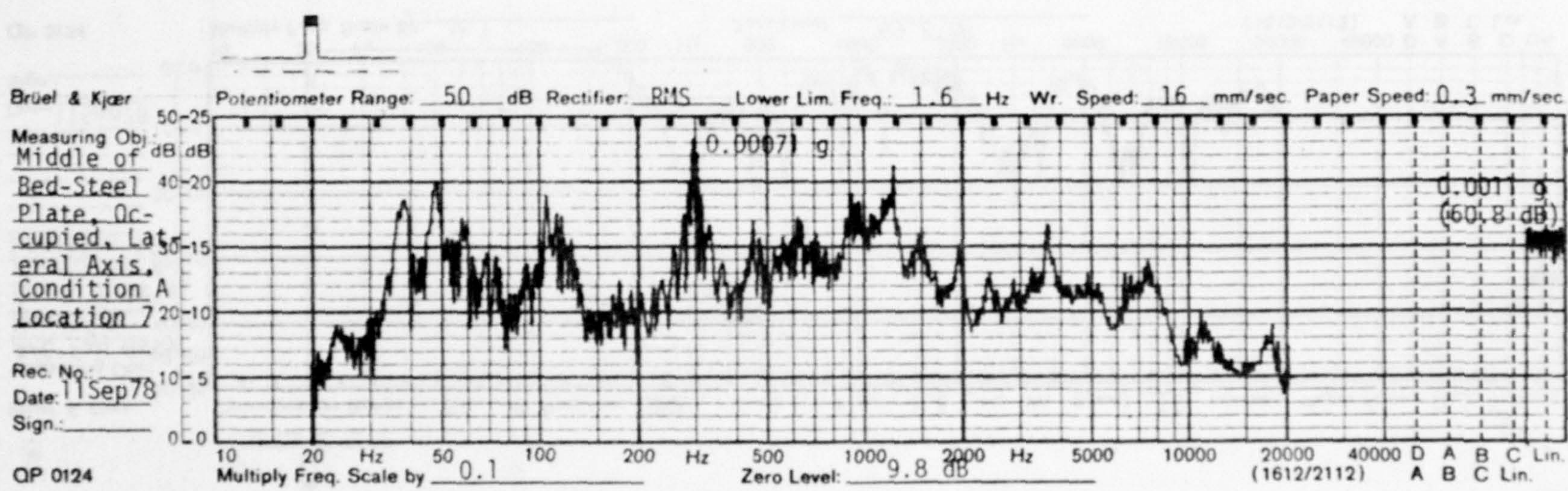


FIGURE 10

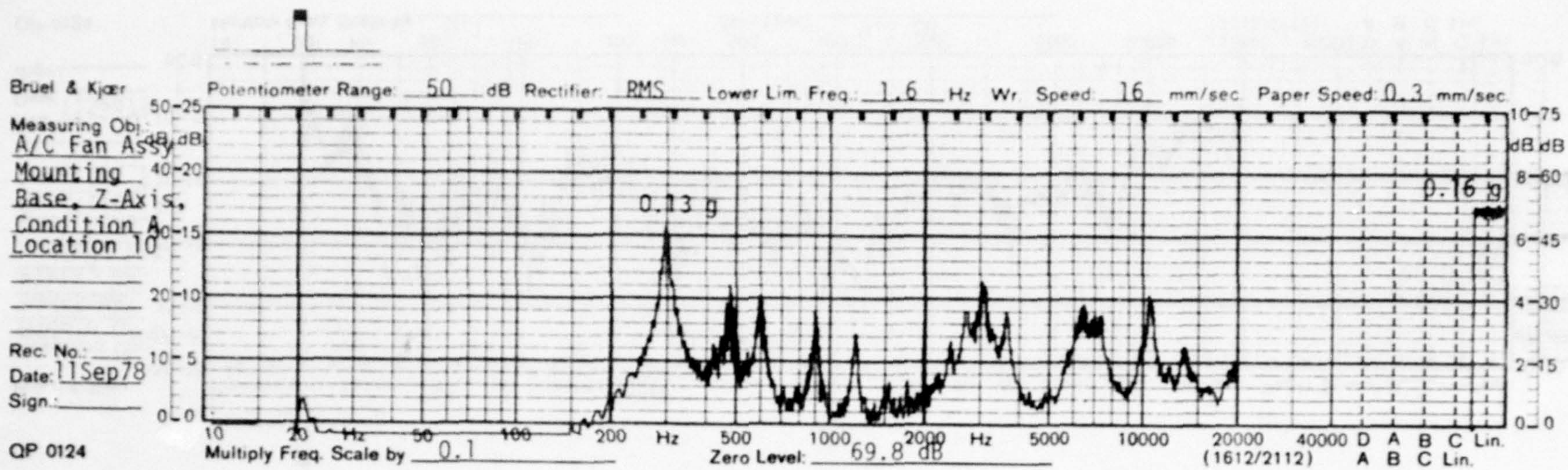


FIGURE 11

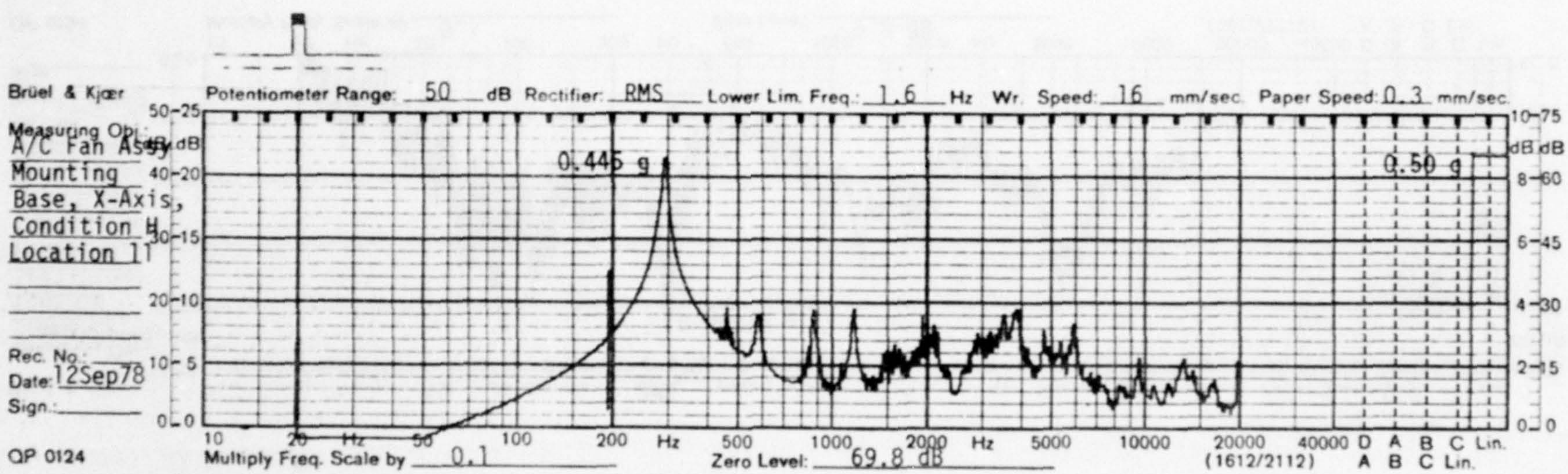


FIGURE 12

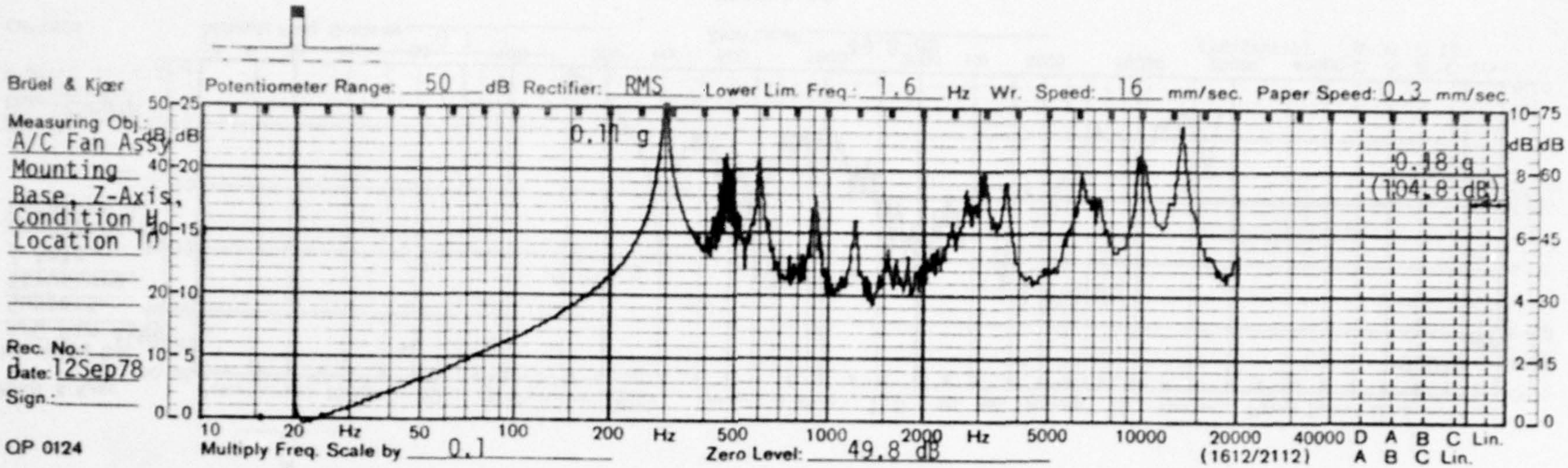


FIGURE 13

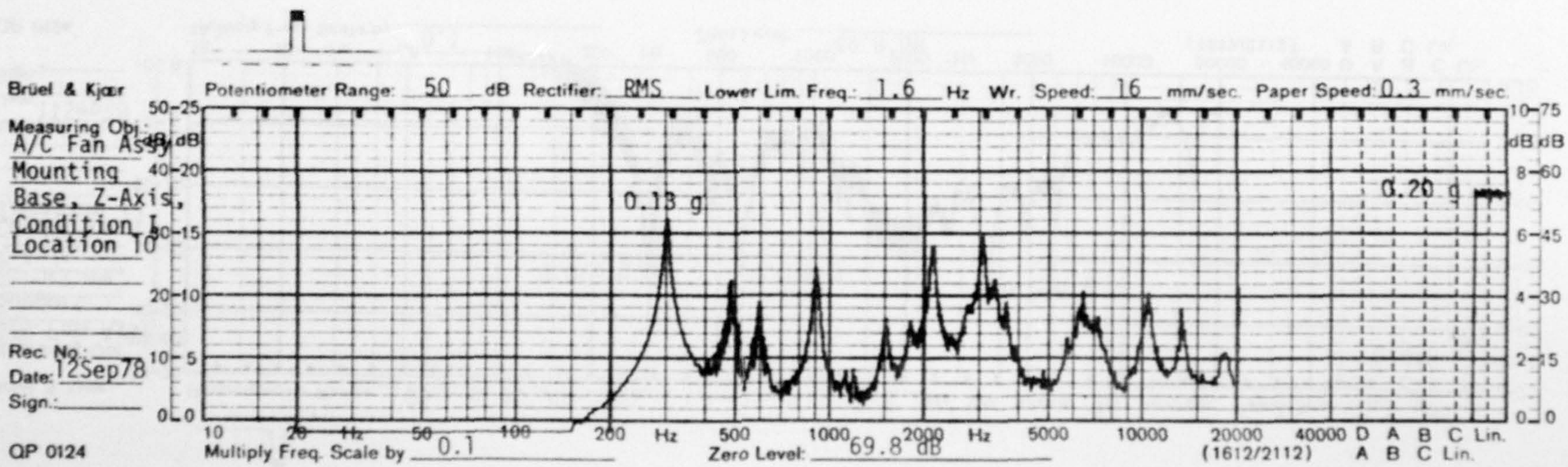


FIGURE 14

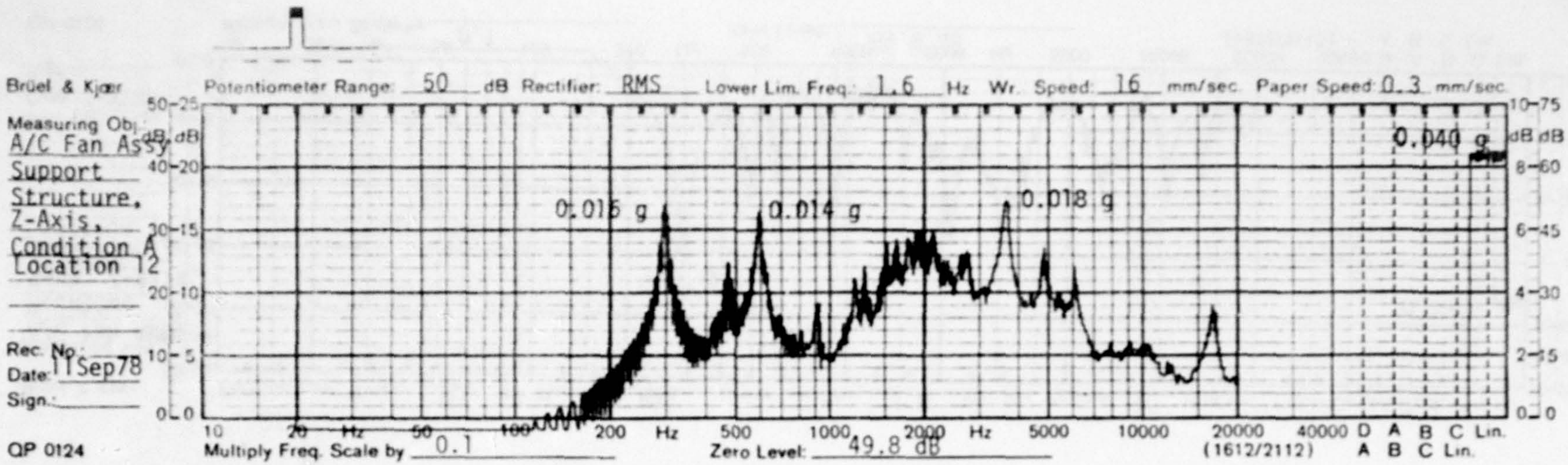


FIGURE 15

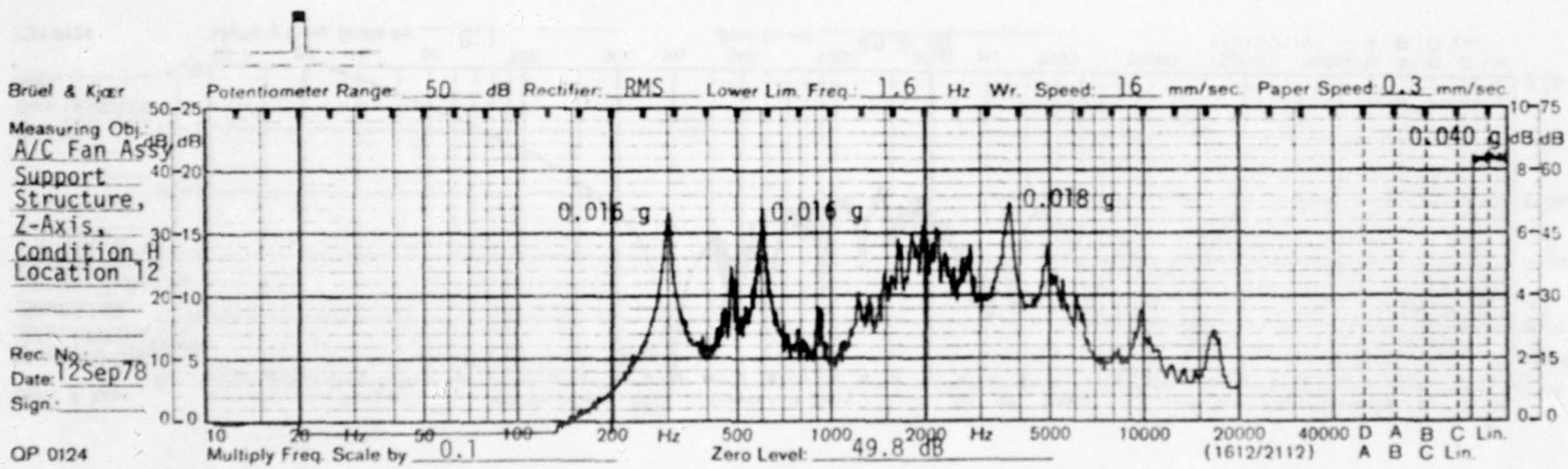


FIGURE 16

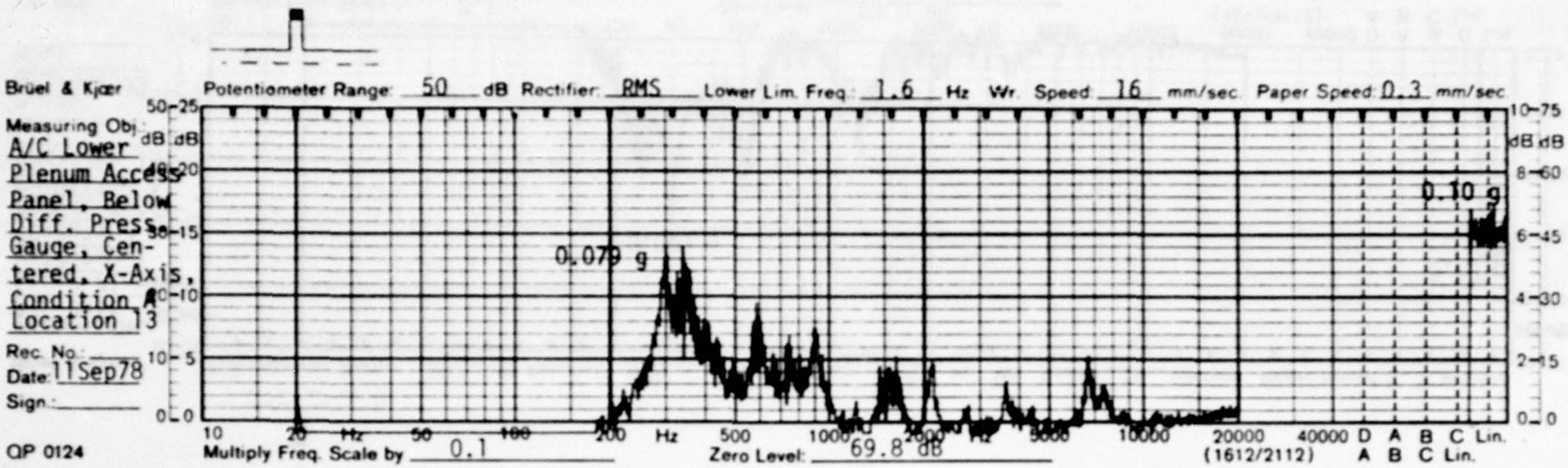


FIGURE 17

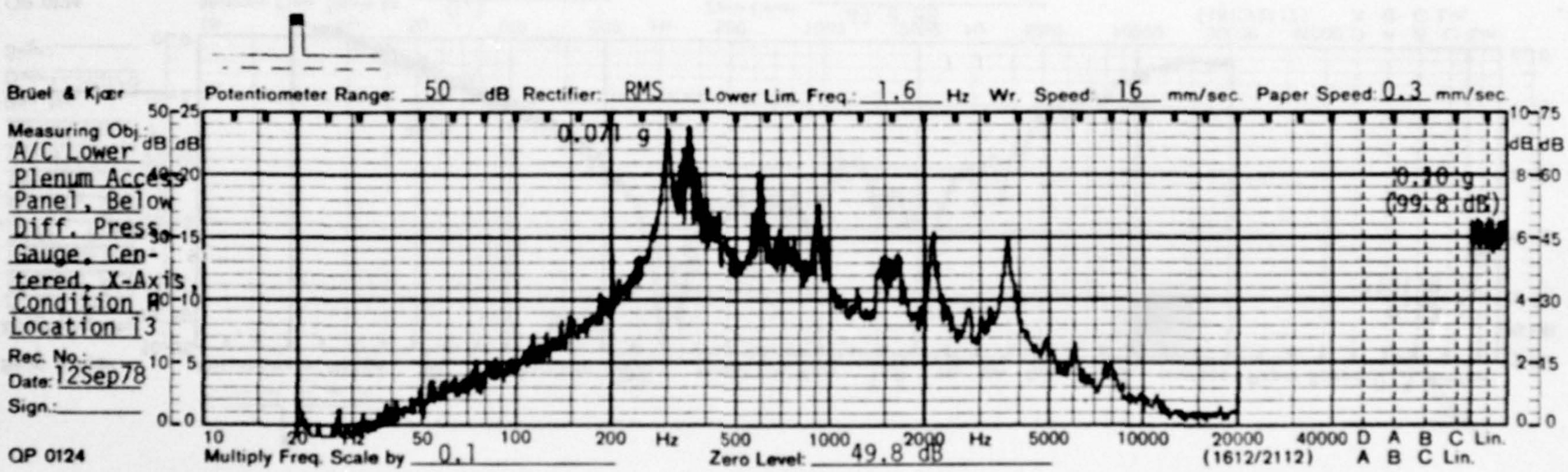


FIGURE 18

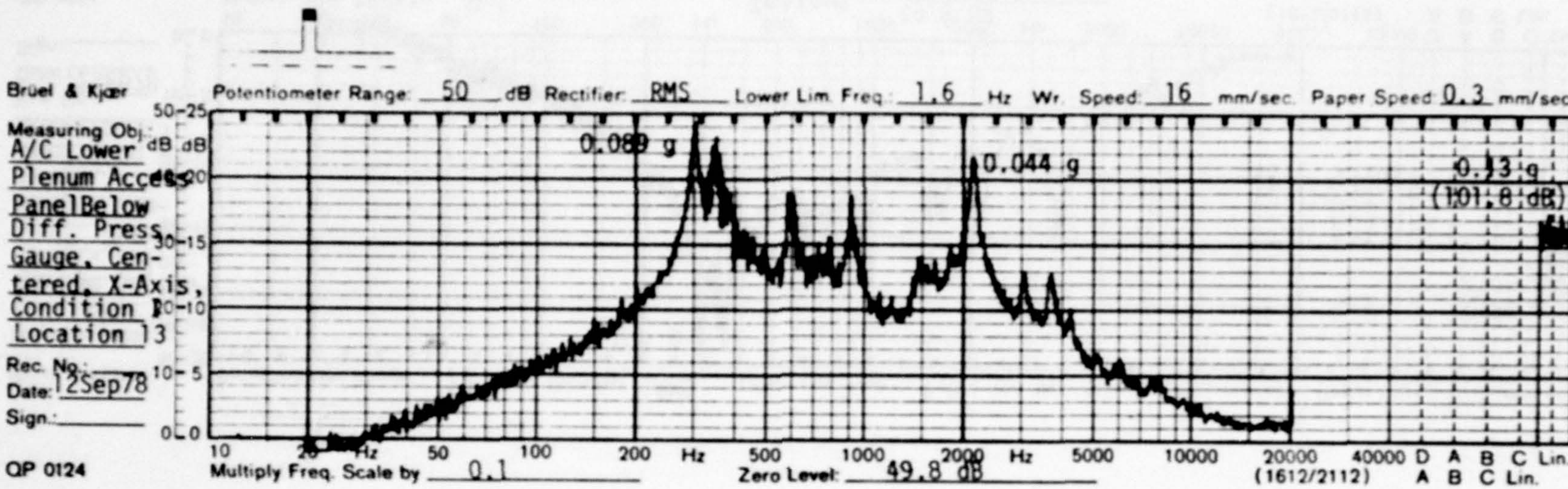


FIGURE 19

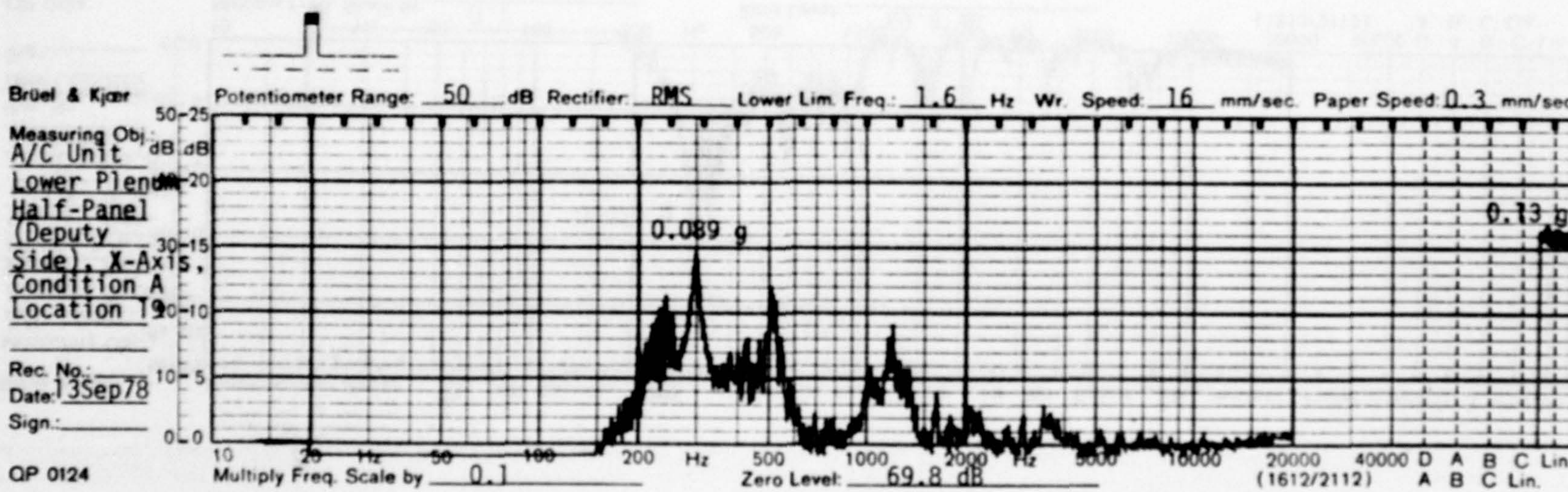


FIGURE 20

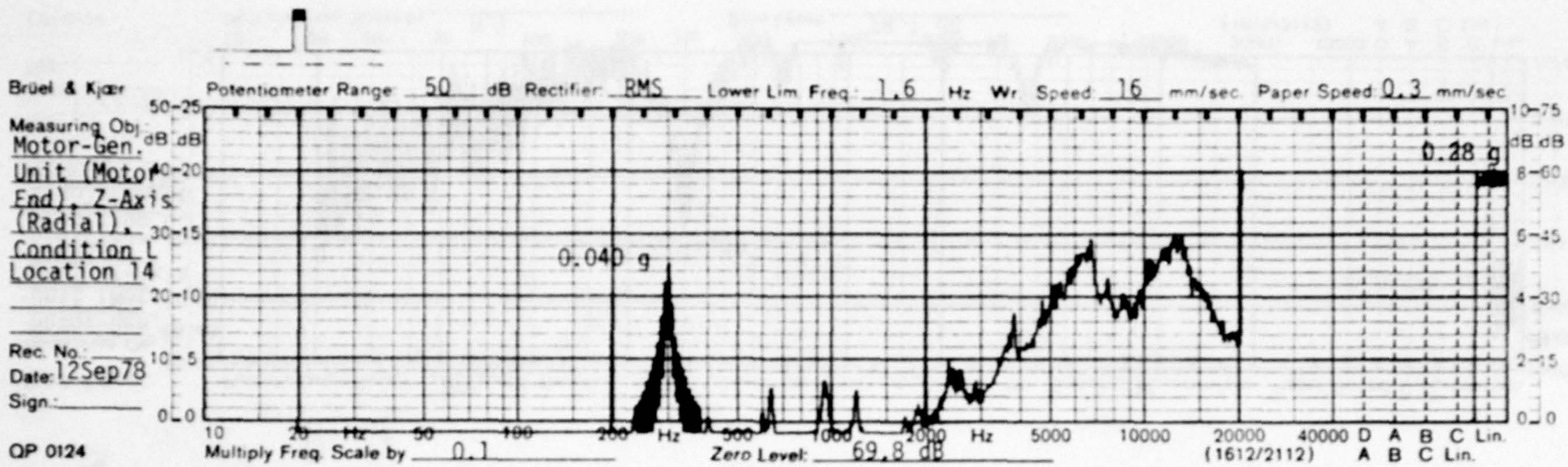


FIGURE 21

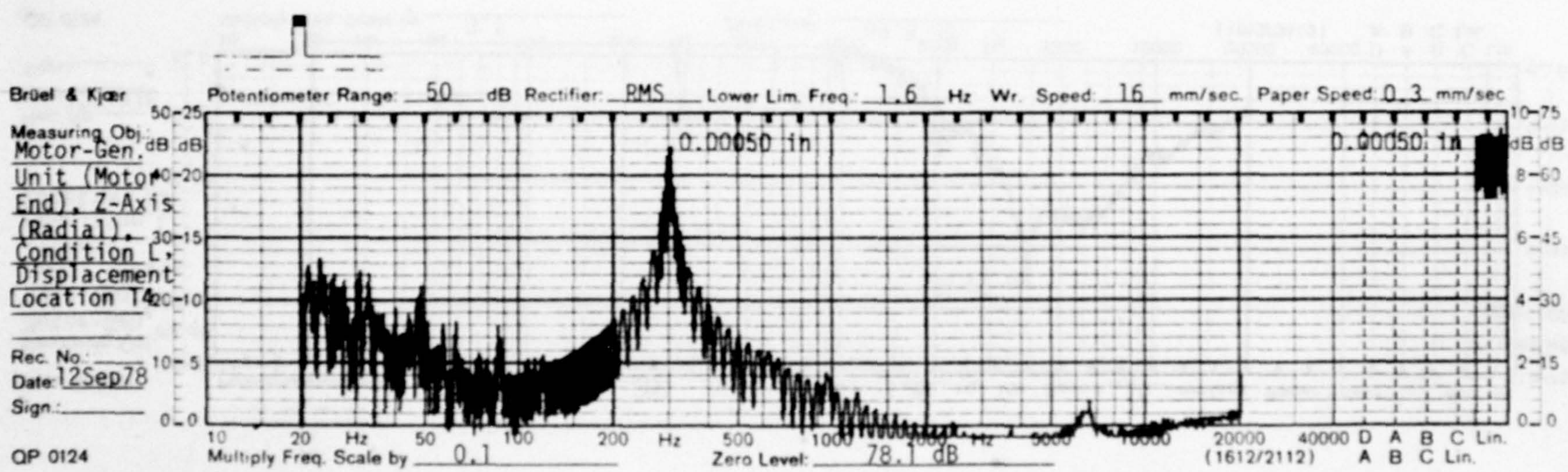


FIGURE 22

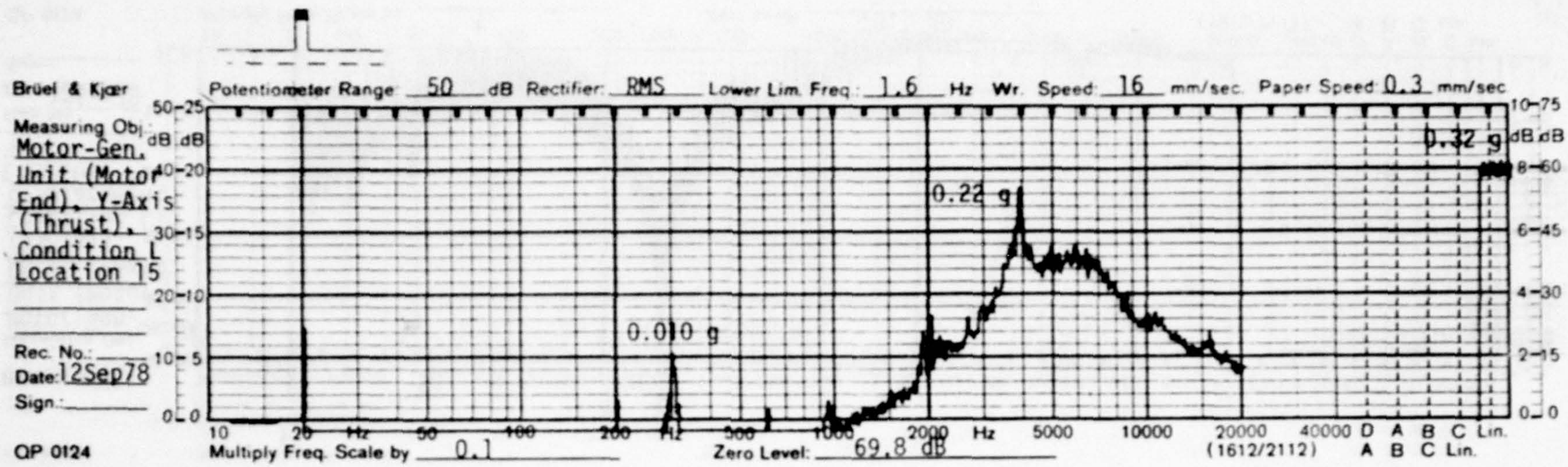


FIGURE 23

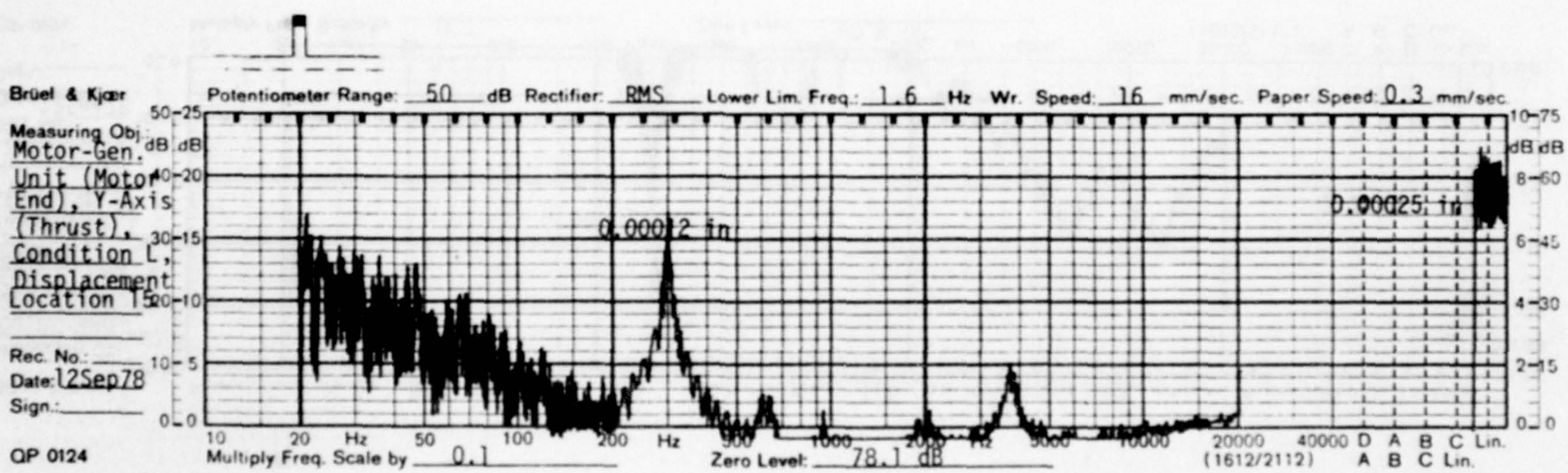


FIGURE 24

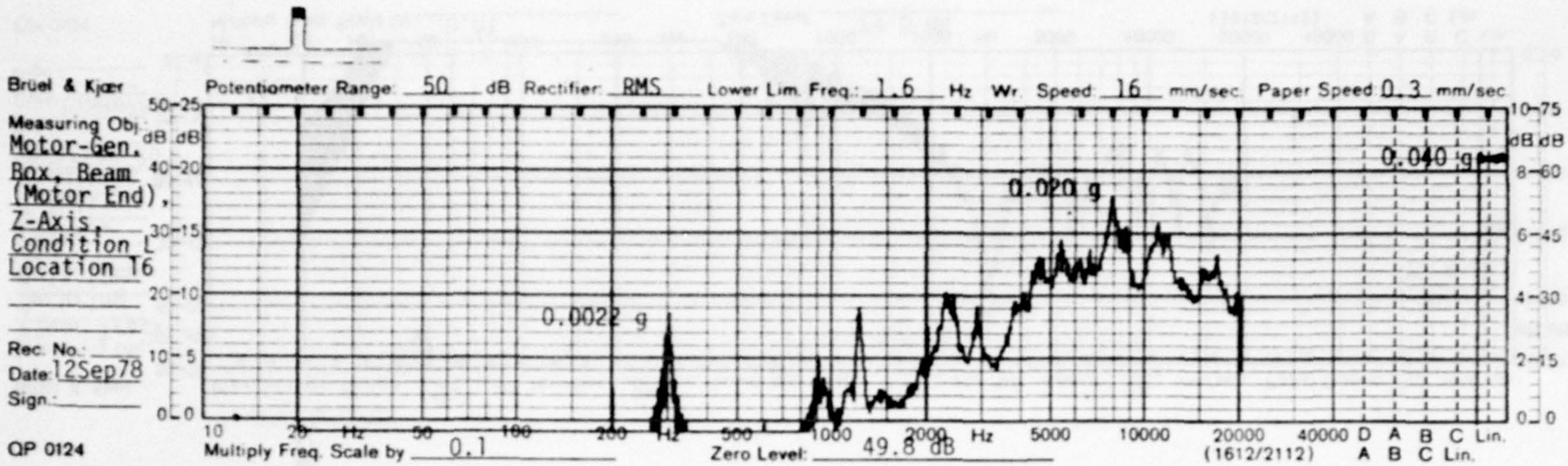


FIGURE 25

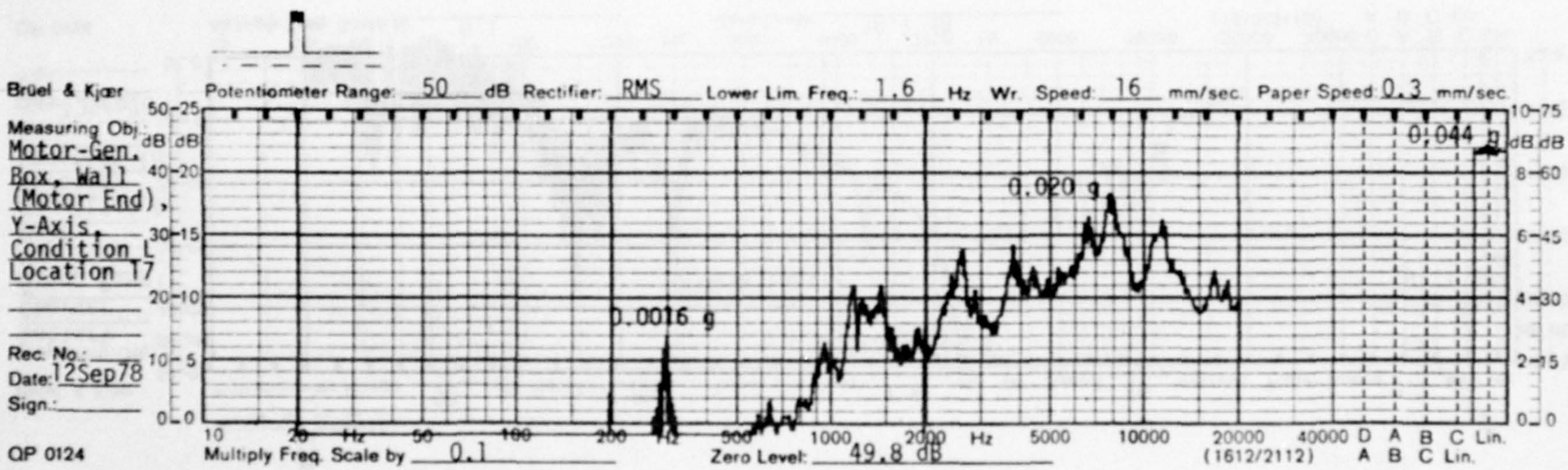


FIGURE 26

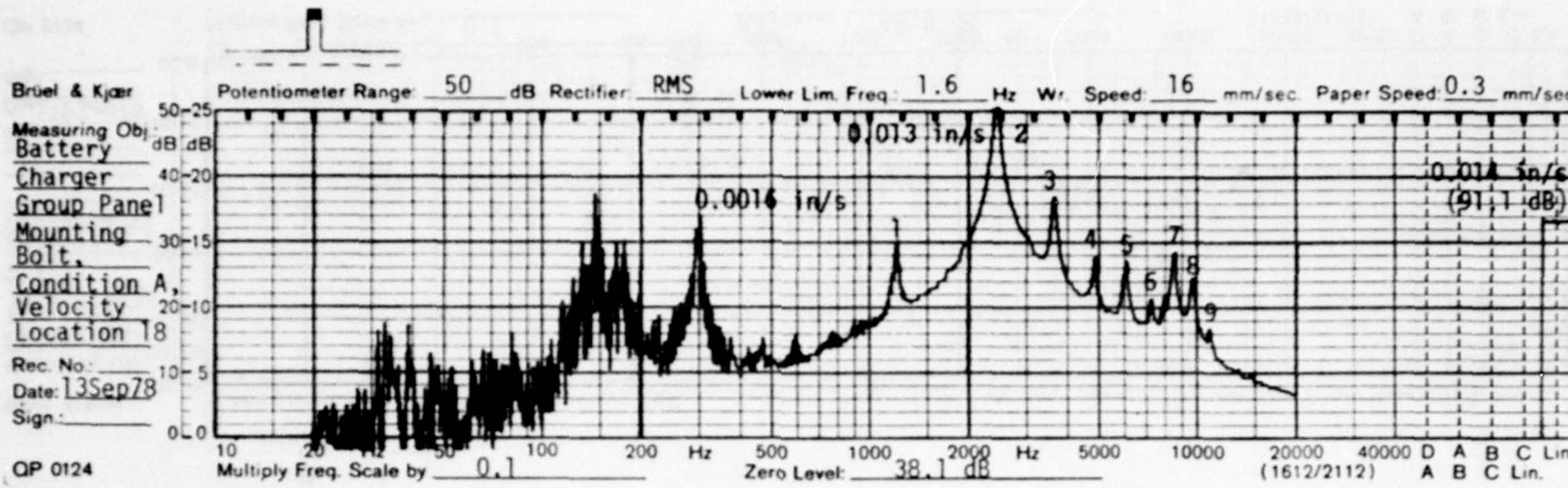


FIGURE 27

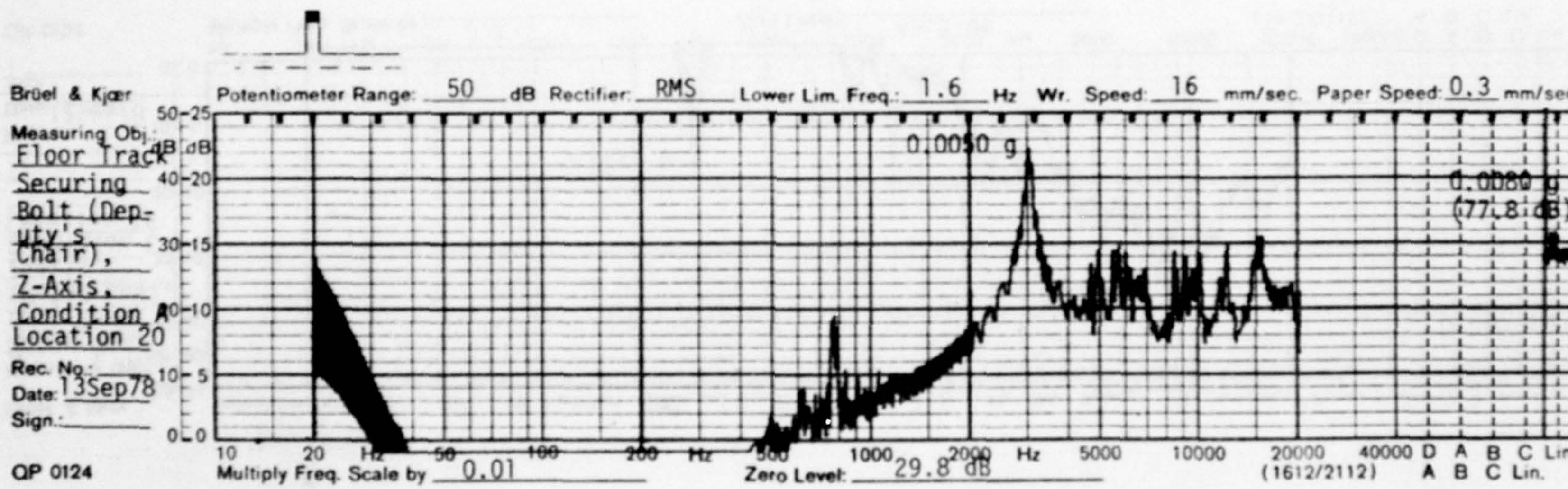
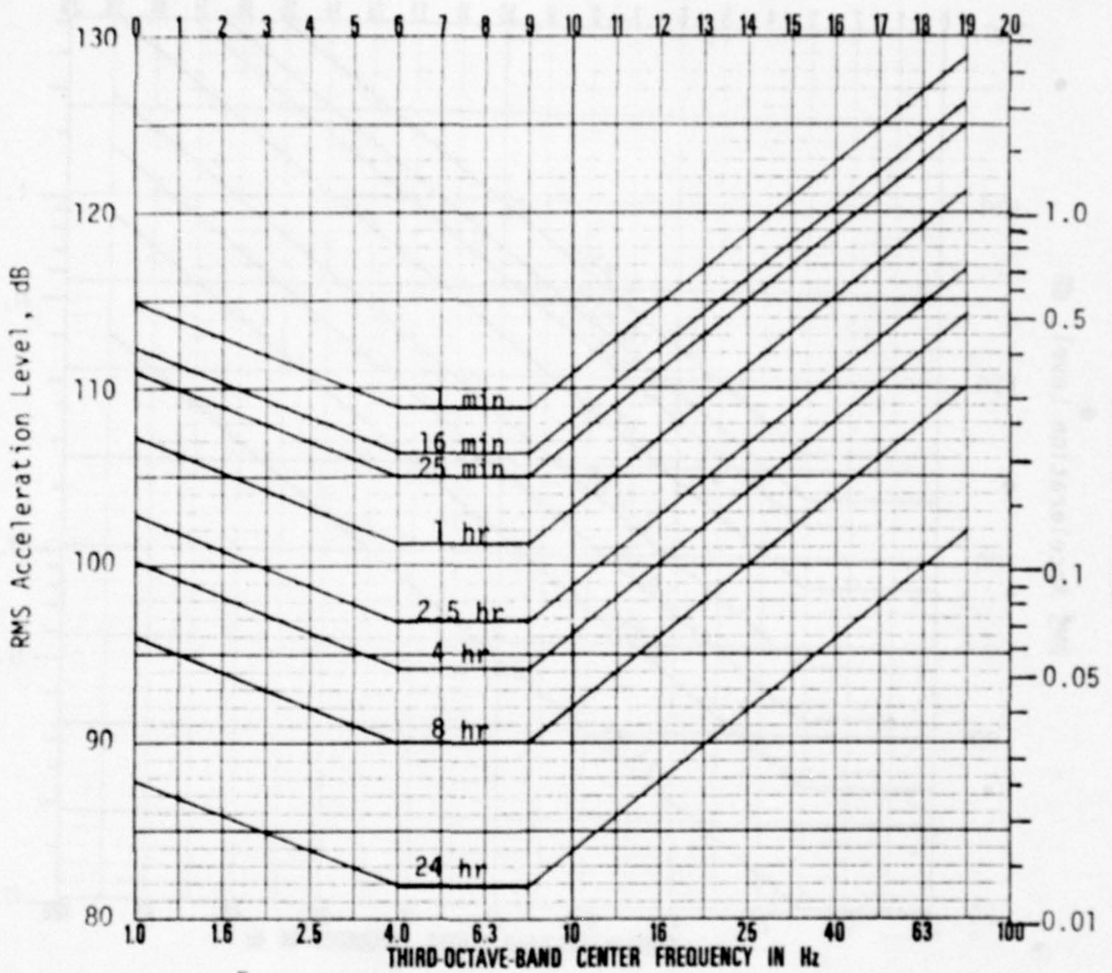


FIGURE 28

FIGURE 29

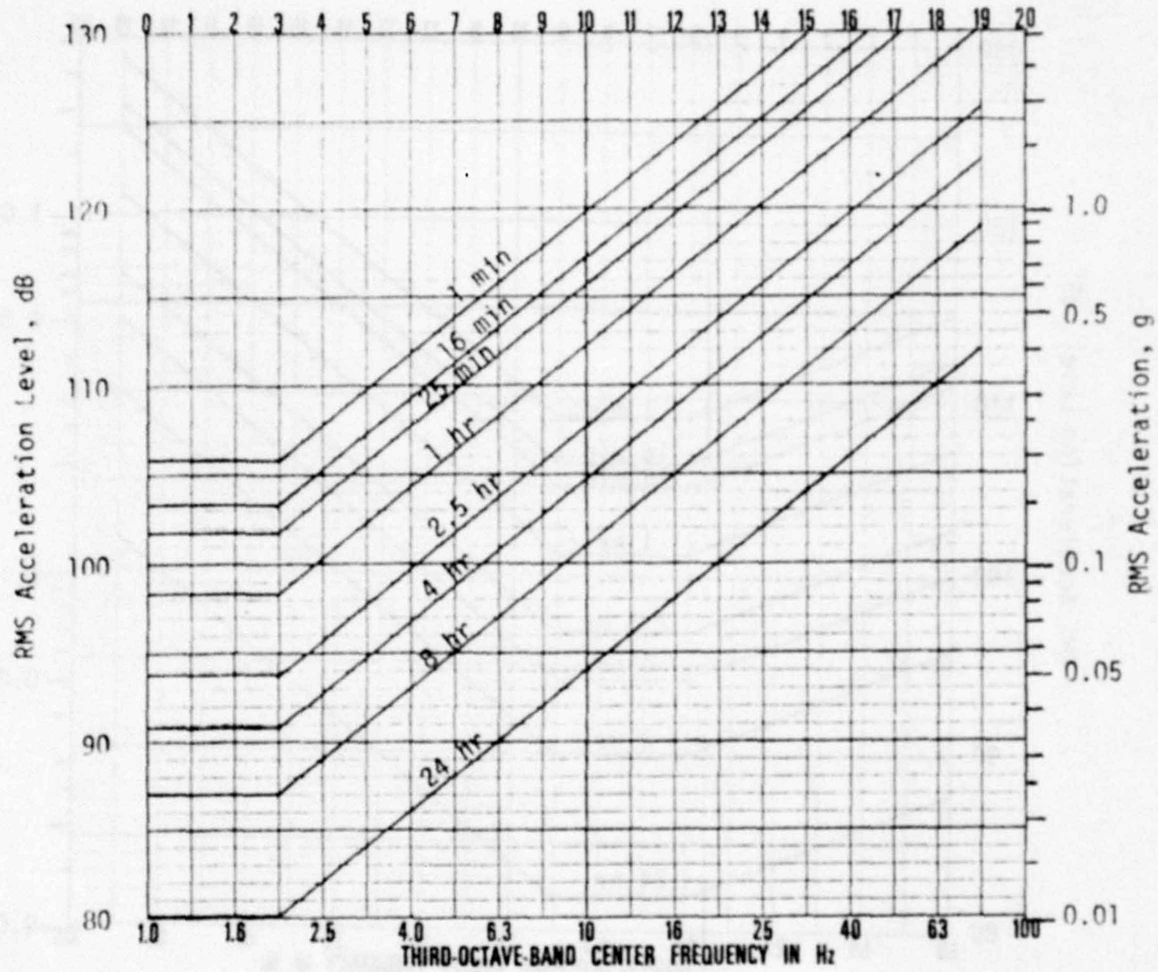


Vertical Vibration Fatigue-Decreased Proficiency Boundary

To obtain

- "Exposure Limits": Add 6 dB (multiply acceleration by 2)
- "Reduced Comfort Boundary": Subtract 10 dB (divide acceleration by 3.15)

FIGURE 30



Horizontal Vibration Fatigue-Decreased Proficiency Boundary

To obtain

- "Exposure Limits": Add 6 dB (multiply acceleration by 2)
- "Reduced Comfort Boundary": Subtract 10 dB (divide acceleration by 3.15)

TABLE 1 - MEASUREMENT LOCATIONS AND TEST CONDITIONS
WS-133 (IP) LAUNCH CONTROL CENTER K-0

Location	Position	Height Above Deck
1	Commander's Console, Seat	Seated, Head Level
2	Commander's Console, Seat	Steel Plate, Occupied
3	Deputy Commander's Console, Seat	Seated, Head Level
4	Isleway in Front of Battery Charger	2 Feet
5	Bed, w/o Acoustic Curtains	Reclining, Head Level
6	Bed, with Acoustic Curtains	Reclining, Head Level
7	Bed, Middle of	Steel Plate, Occupied
8	Isleway Between Air Conditioning Unit and Bed	4 Feet
9	Floor Hatch (Access to Below Deck)	2 Feet
10	Air Conditioning Unit Fan Assembly (S-3) Mounting Base	Z-Zxis
11	Air Conditioning Unit Fan Assembly (S-3) Mounting Base	X-Axis
12	Air Conditioning Unit Fan Assembly (S-3) Support Structure	Z-Axis
13	Air Conditioning Unit Lower Plenum Vertical Access Panel Below Differential Pressure Gauge, Centered in Panel (Bed Side of A/C Unit)	X-Axis
14	Motor-Generator Unit (Motor End)	Z-Axis (Radial)
15	Motor-Generator Unit (Motor End)	Y-Axis (Thrust)
16	Motor-Generator Box, Beam (Motor End)	Z-Axis

Location	Position	Height Above Deck
17	Motor-Generator Box, Wall (Motor End)	Y-Axis
18	Battery Charger Group Panel Mounting Bolt	No. 6 From Bottom on Left Edge of Panel
19	Air Conditioning Unit Lower Plenum Half-Panel (Deputy Side)	X-Axis
20	Floor Track Securing Bolt, Deputy's Chair	Last Bolt on Outside Track Towards Blast Door, Z-Axis

Condition	Operating Equipment
A	Motor-Generator Set (60 & 420 Hz Loads) Air Conditioning Unit (AC Motor - Commercial Power) Room Heater Fan UHF Radio Set Battery Charger (160 VDC)
B	Motor-Generator Set (60 & 420 Hz Loads) Air Conditioning Unit (AC Motor - Commercial Power) Room Heater Fan UHF Radio Set Battery Charger (160 VDC) Signal Data Recorder Printer
C	Motor-Generator Set (60 & 420 Hz Loads) Air Conditioning Unit (AC Motor - Commercial Power) Room Heater Fan UHF Radio Set
D	Motor-Generator Set (60 & 420 Hz Loads) Air Conditioning Unit (AC Motor - Commercial Power) Room Heater Fan
E	Motor-Generator Set (60 & 420 Hz Loads) Air Conditioning Unit (AC Motor - Commercial Power) Battery Charger (160 VDC)
F	Motor-Generator Set (60 & 420 Hz Loads) Air Conditioning Unit (AC Motor - Commercial Power) UHF Radio Set

Condition	Operating Equipment
G	Motor-Generator Set (60 & 420 Hz Loads) Air Conditioning Unit (AC Motor - Commercial Power) Signal Data Recorder Printer
H	Air Conditioning Unit (AC Motor - Commercial Power)
I	Air Conditioning Unit (DC Motor - Battery Power)
J	Room Heater Fan
K	Air Conditioning Unit (AC Motor - Commercial Power) Battery Charger (160 VDC)
L	Air Conditioning Unit (AC Motor - Commercial Power) Motor-Generator Set (No Load)
M	LCC Powered Down (No LCC Equipment Operating)

TABLE 2 - TEST MATRIX

Operating Equipment

Measurement Location	A	B	C	D	E	F	G	H	I	J	K	L	M
1	N			N	N	N							
2	V												
3	N	N		N			N			N			
4											N		N
5	N						N						
6	N		N		N		N						
7	V												
8	N							N	N			N	
9								N	N			N	
10	V							V	V				
11								V					
12	V							V					
13	V							V	V			V	
14												V	
15												V	
16												V	
17												V	
18	V												
19	V												
20	V												

N - Noise Measurement
V - Vibration Measurement

TABLE 3 - RESULTS OF PERSONAL NOISE DOSIMETRY ON THE CAPSULE COMMANDER AT LCC K-0

Sample Number	ECSL, dBA*
1	83
2	86
3	84
4	75
5	82
6	77
7	70
8	79
9	71
10	81
11	77
12	82
13	68
14	73
15	82
16	80
17	80
18	79
19	81

Arithmetic Mean	78 dBA
Standard Deviation	5.0 dB
95% Confidence Interval	$\pm$ 2.4 dB
95% Upper Confidence Limit	80.0 dBA

* 4 dB exchange rate, AFR 161-35, Table 3.

TABLE 4 - RESULTS OF PERSONAL NOISE DOSIMETRY ON THE DEPUTY COMMANDER AT LCC K-O

Sample Number	ECSL, dBA*
1	81
2	78
3	81
4	77
5	88
6	72
7	75
8	79
9	65
10	84
11	84
12	83
13	69
14	79
15	80
16	79
17	75
18	78
Arithmetic Mean	78 dBA
Standard Deviation	5.6 dB
95% Confidence Interval	$\pm$ 2.8 dB
95% Upper Confidence Limit	80.3 dBA

* 4 dB exchange rate, AFR 161-35, Table 3.

TABLE 5 - OCTAVE BAND SOUND LEVELS

Location/ Condition	Octave Band Center Frequency, Hz 31.5	63	125	250	500	1000	2000	OASL(A), dBA	OASPL, dB	PSIL, dB
1/A	82	74	66	66	61	58	57	65	85	59
1/D	80	74	66	62	60	56	54	62	86	57
1/E	80	72	65	59	59	56	54	61	84	56
1/F	82	73	65	60	61	57	56	63	83	58
3/A	85	74	68	64	64	61	60	67	86	61
3/B	84	73	70	73	69	69	68	73	85	69
3/D	83	74	68	62	60	58	58	64	84	58
3/G	83	72	69	73	69	67	67	73	85	68
3/J	60	56	62	53	50	50	47	54	65	49
4/K	81	74	72	65	57	48	46	61	82	50
4/M	45	46	54	48	46	32	28	46	57	35
5/A	84	74	73	62	60	57	55	65	85	57
5/G	84	74	72	61	61	58	56	64	85	58
6/A	85	74	70	60	59	55	50	61	85	55
6/C	84	75	69	60	59	56	51	62	85	55
6/E	84	74	68	59	58	55	51	61	85	55
6/G	84	74	67	60	59	56	52	61	85	56
8/A	85	73	73	68	65	60	58	67	86	61
8/H	83	72	69	63	57	47	44	59	84	49
8/I	84	72	69	64	57	47	44	60	85	49
8/L	84	72	70	63	62	59	56	65	84	59
9/H	86	76	68	59	54	49	44	58	88	49
9/I	88	75	68	60	54	48	44	58	88	49
9/L	87	76	73	73	76	77	74	80	89	76

OASL(A) - A-weighted Overall Sound Level, dBA
OASPL - Overall Sound Pressure Level, dB
PSIL - Preferred Speech Interference Level,dB

TABLE 6 - MOTOR-GENERATOR SET MACHINERY CONDITION

Direction	Frequency, Hz	RMS Velocity, in/sec	Vibration Severity
Radial	30	0.08	Fair
Radial	720	0.007	Very Smooth
Radial	1200	0.004	Extremely Smooth
Axial (Thrust)	30	0.02	Very Good
Axial (Thrust)	600	0.009	Very Smooth

TABLE 7 - GENERAL ROTARY MACHINERY VIBRATION SEVERITY CRITERIA

RMS Velocity Range in/sec	RMS Velocity Range dB	Vibration Severity
0.0049	79	Extremely Smooth
0.0049 - 0.0098	79 - 85	Very Smooth
0.0098 - 0.0196	85 - 91	Smooth
0.0196 - 0.0392	91 -97	Very Good
0.0392 - 0.0785	97 - 103	Good, Normal Operation
0.0785 - 0.157	103 - 109	Fair
0.157 - 0.314	109 - 115	Slightly Rough, Possible Problem
0.314 - 0.628	115 - 121	Rough, Failure Near
0.628	121	Very Rough, Shutdown

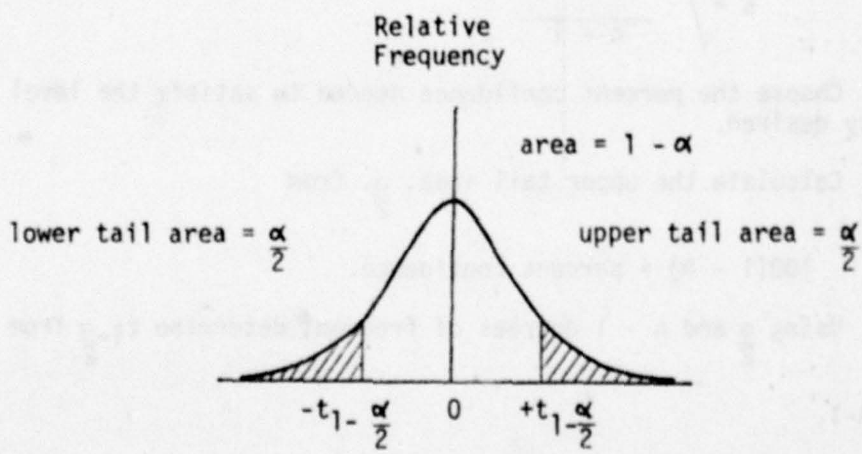
APPENDIX A - TESTS USING THE STUDENT'S t-STATISTIC FOR SMALL SAMPLE POPULATIONS

PART I - Method for Determining when Data Acquisition is Complete

1. Oftentimes it is difficult to judge when enough samples have been taken to adequately define the true mean of the population; the basic assumption being that the sample population, such as workplace noise, is normally distributed. Therefore, a method based on the 2-tailed Student's t-distribution for small sample populations is used for this purpose. Statistics based on a standard normal distribution are not satisfactory because of the small number of samples (i.e., less than 30).

2. The procedure entails: First, arbitrarily choosing the values of two quantities: (a) the percent confidence (usually 90 or 95%) that a certain confidence limit centered about the sample population mean, $\overline{x}$, will contain the true population mean, μ, and (b) the confidence limit itself (usually $\pm$ 3 dB); second, calculating a confidence limit based on the chosen percent confidence level, sample standard deviation, and sample size, and finally, comparing the calculated confidence limit against the chosen value each time a new sample is acquired. (Generally, the confidence limit will tend towards smaller values as additional data are gathered.) Data acquisition can end when the calculated limit equals or falls below the chosen one.

3. The following are definitions of the symbols used:



a. The area $1-\alpha$ is defined as the confidence level that a certain confidence interval centered about the sample mean, $\overline{x}$, contains the true mean, μ, of the standard normal distribution.

b. The percent confidence is defined by the term $100(1 - \alpha)$.

c. $t_{1-\frac{\alpha}{2}}$ is defined as the $100\ (1 - \frac{\alpha}{2})$ percentile of the t-distribution with n - 1 statistical degrees of freedom.

d. $\pm\, t_{1-\frac{\alpha}{2}} \dfrac{s}{\sqrt{n}}$ is defined as the confidence limit.

e. $\overline{x} \pm t_{1-\frac{\alpha}{2}} \dfrac{s}{\sqrt{n}}$ is defined as the confidence interval for the true population mean, μ.

4. Now proceed as follows:

a. Calculate an arithmetic average, $\overline{x}$, from the acquired noise data using

$$\overline{x} = \frac{\Sigma\, x_i}{n}, \text{ where } \quad x_i = \text{individual measured noise level}$$

$$n = \text{sample size}$$

b. Calculate the standard deviation, s, using

$$s = \sqrt{\frac{\Sigma\, (\overline{x} - x_i)^2}{n - 1}}$$

c. Choose the percent confidence needed to satisfy the level of accuracy desired.

d. Calculate the upper tail area, $\frac{\alpha}{2}$, from

$$100(1 - \alpha) = \text{percent confidence.}$$

e. Using $\frac{\alpha}{2}$ and n - 1 degrees of freedom, determine $t_{1-\frac{\alpha}{2}}$ from Table A-1.

f. Calculate the limits of the confidence interval based on the chosen percent confidence level using

$$\pm\, t_{1-\frac{\alpha}{2}} \frac{s}{\sqrt{n}}$$

g. Arbitrarily choose limits, e, on an interval which you desire to contain the true population mean, μ, and with the percent confidence chosen in step d. above.

h. Data acquisition can stop when the condition

$$\pm\, t_{1-\frac{\alpha}{2}} \frac{s}{\sqrt{n}} \leq e$$

is satisfied.

5. By way of example, some of the actual data collected during personal noise dosimetry of the capsule commander (Table 3) was used to develop Table A-2. The arithmetic averages, standard deviations, and confidence limits shown for a particular sample were calculated from all sample data. A 95% confidence interval and a value of e = 3 dB were chosen. After the sixteenth sample was acquired, the value of

$$t_{1-\frac{\alpha}{2}} \frac{s}{\sqrt{n}}$$

was calculated using n - 1 = 15 degrees of freedom, s = 5.4 dB, and $t_{1-\frac{\alpha}{2}} = 2.131$ (from Table A - 1), yielding 2.9 dB. Since this value was less than 3 dB, the condition defined in paragraph 4.h. above was satisfied and data acquisition could end. In the actual case (Table 3) three more samples were collected; however, data acquisition could have stopped at 16 observations. By collecting 19 samples, the 95% confidence interval was reduced from $\pm$ 2.9 dB with 16 observations to $\pm$ 2.4 dB with 19 observations. For the 16 observation example, one is 95% confident that the interval 78 dBA $\pm$ 2.9 dB contains the true population mean of the Equivalent Continuous Sound Levels (ECSL).

PART II - Comparison of the Mean of the Measured Data with a Standard

1. Previously, the discussion was concerned with the variability of sampled data about the mean; i.e., confidence interval, in order to determine when enough samples have been taken. The following discussion will deal with placing either an upper bound or a lower bound on the mean in order to allow comparison with a standard to determine compliance or noncompliance.

2. The purpose of acquiring data is to determine the true population mean, μ, to describe the environment. Because of limited sample resources, only the sample mean, $\overline{x}$, can be obtained which is an estimate of μ. While μ is a fixed quantity, $\overline{x}$ has a degree of variability associated

with it due to sampling techniques. It is necessary to establish with a certain level of confidence the sample mean and its maximum upper range or its minimum lower range. These limits are the Upper Confidence Limit (UCL), and the Lower Confidence Limit (LCL), respectively. This is done by using the 1-tailed t-test with the data to state with a certain degree of certainty that the true population mean, μ, either does not exceed the UCL or does not fall below the LCL. The UCL or LCL is compared with the standard to determine acceptability.

3. The definitions are the same as in Part I above except the percentile $t_{1-\alpha}$ and only one tail, whose area is now defined as α, is used.

4. Proceed as follows:

a. Perform steps 4.a through 4.e in Part I above, except use α instead of $\frac{\alpha}{2}$.

b. Calculate either

$$UCL = \overline{x} + t_{1-\alpha} \frac{s}{\sqrt{n}} \quad \text{if } \overline{x} < \text{standard,}$$

or

$$LCL = \overline{x} - t_{1-\alpha} \frac{s}{\sqrt{n}} \quad \text{if } \overline{x} > \text{standard,}$$

but not both.

c. Now classify the exposure by comparing the UCL or the LCL against the standard as follows:

(1) If UCL > standard - At the chosen confidence level the exposure is possibly above the standard.

(2) If UCL $\leq$ standard - At the chosen confidence level the exposure is below the standard.

(3) If LCL > standard - At the chosen confidence level the exposure is above the standard.

(4) If LCL $\leq$ standard - At the chosen confidence level the exposure is possibly above the standard.

d. If it is not possible to determine overexposure, additional sampling or accepting a lower level of confidence may be required.

5. Continuing with the example in Part I above, n - 1 = 15 degrees of freedom, s = 5.4 dB, and $t_{1-\alpha}$ = 1.753 (Table A-1), giving

$$95\%\ UCL = 78 + 2.4 = 80.4\ dBA.$$

This equation shows that one has a 95% confidence that the true ECSL does not exceed 80.4 dBA. If one assumes the 16-hour standard (AFR 161-35, Table 3) of 80 dBA, then

$$UCL > standard.$$

This implies a possible overexposure for which additional sampling or a lowering of the confidence level (say, to 90%) would be necessary. However, in this case rounding off 80.4 dBA to 80 dBA is proper, given the insignificant impact of a fraction of a decibel on the human ear. This would allow compliance with the regulation.

TABLE A - 1 THE STUDENT'S t-DISTRIBUTION*

Degrees of Freedom	Upper-tail Area 0.05	0.025	0.005
1	6.314	12.706	63.657
2	2.920	4.303	9.925
3	2.353	3.182	5.841
4	2.132	2.776	4.604
5	2.015	2.571	4.032
6	1.943	2.447	3.707
7	1.895	2.365	3.499
8	1.860	2.306	3.355
9	1.833	2.262	3.250
10	1.812	2.228	3.169
11	1.796	2.201	3.106
12	1.782	2.179	3.055
13	1.771	2.160	3.012
14	1.761	2.145	2.977
15	1.753	2.131	2.947
16	1.746	2.120	2.921
17	1.740	2.110	2.898
18	1.734	2.101	2.878
19	1.729	2.093	2.861
20	1.725	2.086	2.845
21	1.721	2.080	2.831
22	1.717	2.074	2.819
23	1.714	2.069	2.807
24	1.711	2.064	2.797
25	1.708	2.060	2.787
26	1.706	2.056	2.779
27	1.703	2.052	2.771
28	1.701	2.048	2.763
29	1.699	2.045	2.756
30	1.697	2.042	2.750

* Table provides the values of $t_{1-\frac{\alpha}{2}}$ that correspond to a given upper-tail area $\frac{\alpha}{2}$ and a specified number of degrees of freedom for a 2-tailed test. Likewise, for a 1-tailed test, the table provides values of $t_{1-\alpha}$ that correspond to a given upper-tail area α.

TABLE A - 2 PERSONAL DOSIMETRY EQUIVALENT CONTINUOUS SOUND LEVEL (ECSL) DATA*

Sample Number	ECSL, dBA	Arithmetic Average ECSL, dBA	Standard Deviation, dB	95% Confidence Interval, dB
1	83	-	-	-
2	86	84	2.1	± 18.9
3	84	84	1.5	± 3.7
4	75	82	4.8	± 7.6
5	82	82	4.2	± 5.2
6	77	81	4.3	± 4.5
7	70	80	5.7	± 5.3
8	79	80	5.3	± 4.4
9	71	79	5.7	± 4.4
10	81	79	5.5	± 3.9
11	77	79	5.2	± 3.5
12	82	79	5.1	± 3.2
13	68	78	5.7	± 3.4
14	73	78	5.6	± 3.3
15	82	78	5.6	± 3.1
16	80	78	5.4	± 2.9

* 4 dB exchange rate, AFR 161-35, Table 3.

APPENDIX B - THE DECIBEL NOTATION

Since noise and vibration measurements are made over wide dynamic ranges (e.g., 6 decades), it becomes difficult to present data using linear scaling. That is, when graphing data, large graphs are required since values of low magnitude are squashed together near the zero axis, making interpretation difficult. Logarithmic scaling allows data covering a wide dynamic range to be graphically presented in a condensed form, and allows the low magnitude values to be given equal weight with respect to the large ones. Also, analysis of acoustic and vibration spectral data is simplified since they often display linear characteristics when using logarithmic scaling.

Accordingly, the type of logarithmic scale used is the decibel (dB) scale which gives the level of the value in decibels above (or below) a reference quantity. As used here, the word "level" will always indicate a logarithm (in dB) of the ratio of a value over a reference quantity, and the logarithm being multiplied by a constant (usually 20). The reference quantity must always be stated. For example, the Sound Pressure Level (SPL) is defined as

$$SPL = 20 \log \frac{p}{p_o}$$

, where p = the root-mean-square sound pressure, and

p_o = reference sound pressure,

20 Pa or 2.90×10^{-9} lb/in^2

NOTES:

a. The units of both pressure values must be the same so that the ratio will be dimensionless.

b. The root-mean-square (rms) value, also called the effective value, is obtained by taking the square root of the arithmetic mean of the squares of the measured values over the measurement time. An rms signal of a certain value will transfer the same amount of power to a load (electrical, acoustical, mechanical, etc.) as a constant (DC) signal having the same magnitude.

APPENDIX C - VIBRATION LEVELS AND REFERENCE QUANTITIES

1. The root-mean-square (rms) vibratory acceleration level, L_a is defined by

$$L_a = 20 \log \frac{a}{a_o}$$, where a = observed rms acceleration, and

a_o = reference acceleration,

$1.02 \times 10^{-6} g = 10^{-5} m/sec^2 =$

$39.4 \times 10^{-5} in/sec^2$

Conversely, the rms vibratory acceleration, a, is obtained from

$$a = a_o 10^{\frac{L_a}{20}}$$

2. Likewise, the rms vibratory velocity and rms displacement (and their respective rms levels) are defined in the same way, except

v_o = reference velocity, 10^{-8}m/sec = 39.4×10^{-8}in/sec, and

d_o = reference displacement, 10^{-11}= 39.4×10^{-11}in.

3. Peak-to-peak levels, L_{pp}, for single frequency sinusoidal signals are related to the rms level, L_{rms}, and the peak level, L_p, by

$L_{pp} - L_{rms} = 9$ dB,

$L_{pp} - L_p = 6$ dB, and

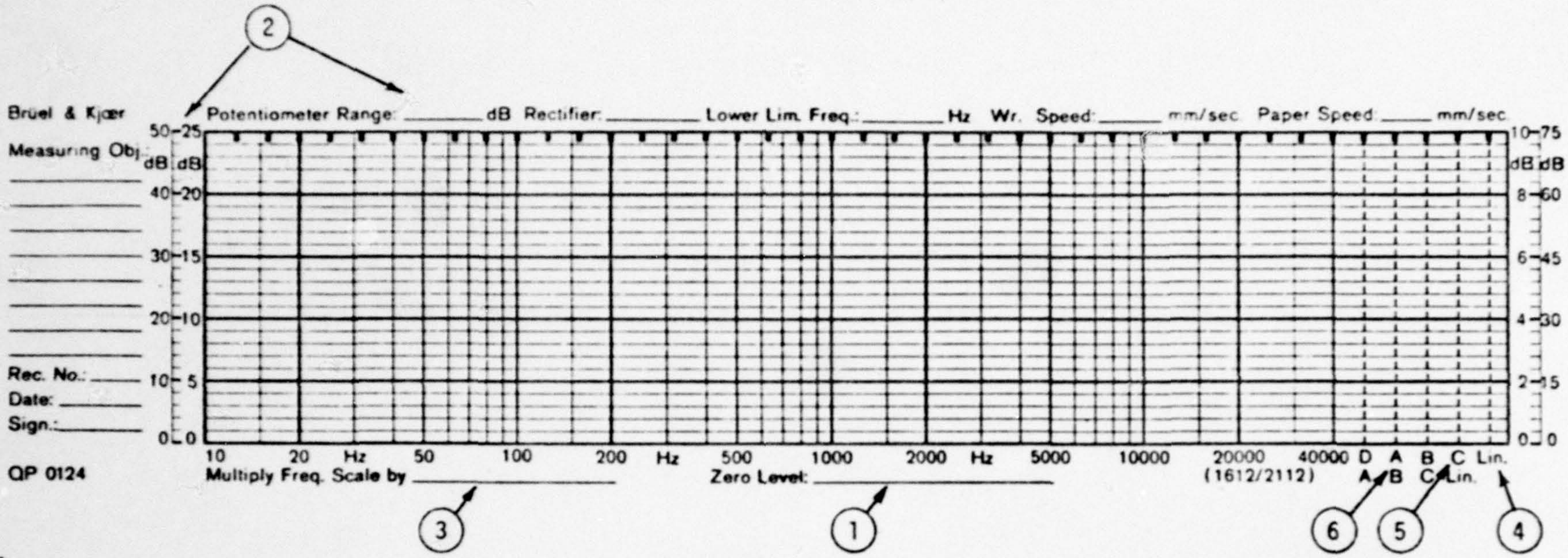
$L_p - L_{rms} = 3$ dB.

4. At any specific vibratory frequency, f, the rms values of acceleration, a, velocity, v, and displacement, d, are related by

$$a = 2 fv = (2 f)^2 d.$$

This relation does not hold for the overall values. However, there is usually one dominant vibration peak in the spectrum which both controls the overall value and is of particular interest (e.g., fundamental frequency of the driving force of the response).

APPENDIX D - HOW TO READ THE B & K STRIP CHART



1. Zero Level - This is the level (dB or dBA) along the x-axis of the chart.
2. Potentiometer Range - This value represents the dynamic range (dB) of the y-axis of the chart.
3. Multiply Freq. Scale by - Multiply the values printed on the x-axis by this value to obtain the proper frequency scaling.
4. Lin. - The level drawn above this space represents the unweighted overall level (dB).
5. C - Same as 4 above except for C-weighted sound level (dBC).
6. A - Same as 4 above except for A-weighted sound level (dbA).

APPENDIX E

DEPARTMENT OF THE AIR FORCE
6570TH AEROSPACE MEDICAL RESEARCH LABORATORY (AFSC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

REPLY TO ATTN OF: BBA 2 May 1977

SUBJECT: Limiting Value for 24-Hour Noise Exposure

TO: AMD/RDC
Brooks AFB TX 78235

1. This correspondence is in response to your letter, same subject, of 23 March 1977. Per your request, we have analysed the possible effects on hearing of the proposed operational change in the alert tours for the crews of the Minuteman Launch Control Center. Based on (1) this laboratory's research into actual 24 hour noise exposures on over 33 subjects, (2) other research effects directly related to the questions that are reported in the literature, and (3) noise measurements provided by SAC of typical 24 hour noise exposures, we conclude that there will not be an increased noise hazard with respect to hearing damage if the alert tour is changed from 12 to 24 hours. The remainder of this letter provides detailed support of this position as well as some suggestions with respect to possible worst case noise situations and to a solution to possible sleep interference problems that may occur for some individuals.

2. Currently the Air Force regulation on Hazardous Noise Exposure (AFR 161-35) specifies that a daily exposure should not be above an equivalent A-weighted sound level of 84 dB for 8 hours or 80 dB for 16 hours. No mention is made in the regulation as to how to assess noise exposures longer than 16 hours, although there is certainly a tacit implication that such daily exposures should not be above an equivalent level of 80 dB. (By equivalent level we mean a constant sound level that should produce the same hazard as the actual time varying noise levels). But in the final analysis, AFR 161-35 was not designed to handle the long duration noise exposure problem because a technology base for establishing such criteria was not available at the time the regulation was drafted.

a. Since the publication of AFR 161-35, we have completed several studies under our long duration noise exposure program, with emphasis on exposures of 24 hours duration. We have concluded from these studies that 24 hour exposures to continuous sound at levels as high as 85 dB (and maybe a few decibels higher) would not be a hazard to hearing if the subject was allowed to recover from the noise for 24 hours in a relatively quiet environment (less than 70 dB). At present 33 subjects have been exposed to continuous noise of 85 dB for 24 hours. While temporary threshold shifts (TTS) in hearing acuity do occur, these shifts have disappeared in 24 hours for all subjects.

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b. We have also shown that time varying noise, which is more typical in the Launch Control Centers, behaves similarly to continuous noise with respect to the effects on hearing. Currently we are performing a study to determine at what noise level a 24 hour noise exposure does not even cause a temporary change in hearing acuity. Such a "no effect" level would be completely safe and thus one would not even have to be concerned that the ear was allowed to recover in a quiet environment. At this time only 7 of 12 subjects have been exposed, however, the preliminary data of these 7 subjects would indicate that approximately 75 dB is such a "no effect" level.

c. Finally, there is the concept of "effective quiet" that has been proposed by some scientists. "Effective quiet" is that continuous level of noise which does not interfere with the normal recovery of TTS from some previous noise exposure. Depending on the spectrum of the noise, the level for "effective quiet" has been shown to be from 69 to 76 dB.

3. With the above considerations of paragraph 2 in mind, the effect on hearing of the typical 24 hour noise exposures expected for the alert crew can be assessed.

a. Analysing the data provided to Capt Stephenson by SAC at the 23 Mar 77 meeting at Offutt AFB, the typical equivalent noise level for the Wings I to V Launch Control Centers (measured at Francis E. Warren) varied from 68 to 72 dB. Typical equivalent noise levels for the Wing VI/Sqdn 20 Launch Control Centers (measured at Grand Forks) varied from 70 to 77 dB. In all cases these levels are below the 80 dB implied by AFR 161-35 and are even normally below our tentative no effect level of 75 dB. Furthermore, the actual spectrum of the noises in the centers show that a considerable part of the noise is in the low frequencies and should be even less hazardous than the measured levels indicate. For these reasons alone, we conclude that these typical exposures are nonhazardous to hearing.

b. Another question, relative to the "effective quiet" concept, is whether the noise environment of the LCC might interfere with recovery of a TTS experienced by a crewman before he entered the LCC area. Since for the spectrum provided, "effective quiet" is approximately 75 or 76 dB, we can safely say that normally the noise exposure in the capsule will not even interfere with recovery of TTS from other outside noise exposures (such as a helicopter ride). Thus even applying a worse case scenario, the typical 24 hour noise exposure of an alert crewman is not hazardous to hearing.

4. There is one remaining question that must be addressed. How typical are the noise exposures which were provided to Capt Stephenson? Via telephone conversations between Capt M. Reed of Grand Forks AFB and the

undersigned it was noted that on some occasions special activities cause heavy use of the HF radio and the printers. In these cases, these sources will dominate the noise exposure of the crewman and may cause noise exposures for 12 or 14 hours that are above those specified by AFR 161-35. However, if such exposures do occur they are a present problem and changing from a 12 to 24 hour tour of duty will not make the problem worse as long as these special activities are kept to 12 or 14 hours. In fact, when the special activity is at the start of the 24 hour tour, the 24 hour duty tour may even be of some benefit since the noise exposure of the crewman for the remaining 12 to 10 hours can be expected to be below that of "effective quiet." At least the crewmember will not be able to expose himself to some high level of recreational noise during the time period following the TTS inducing exposure.

5. Two suggestions are offered to the SAC Command Surgeon with respect to reducing the impact of noise on the alert crewman:

a. Regardless whether or not the 24 hour duty is implemented the noise exposure during special activities that cause considerable HF radio or printer activity should be investigated and the criteria of AFR 161-35 applied. Since supposedly these are infrequent occasions, an equivalent level of 4 dB greater (or a dose of 200%) could be considered as still acceptable. However, we feel that greater exposure levels should require some corrective action.

b. If the 24 hour duty tour is used, then during the rest or sleeping period earplugs should be provided to these crewmen that experience some difficulty sleeping because of the noise. Certainly we expect some individuals to find the noise levels somewhat more bothersome than others to sleeping.

6. Please call Lt Col Johnson or Capt Mark Stephenson if you have any questions (513-255-3660).

Daniel L. Johnson

DANIEL L. JOHNSON, Lt Col, USAF
Biological Acoustics Branch
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